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Deployed Force Waste Management

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ABSTRACT

This report examines a range of science and technology issues concerning waste management for deployed land forces. Within this waste management context, the report outlines the functional requirements of a deployed force, the status of Australian research and development, deployable technology options, and approaches to systems modelling.

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Executive Summary

The Army Science and Technology Master Plan (ASTMP) 2004-2007 defines the Force Research Area Capability 9 (FRAC L9) – Combat Service Support as comprising all of the systems, processes, procedures and personnel required to sustain land-based operations within a theatre of operations. A component of this FRAC include Army's interest and requirements for scientific support concerning deployed force waste management.

Included in this report are the initial outcomes of DSTO Task ARM 03/101 (Logistic Waste Management Studies), which analysed a collection of deployed force waste management issues, principally related to the land environment. The work has been undertaken on behalf of the Director General Land Development (DGLD).

Waste management is not the core business of deployed forces. However, it has become increasingly important to consider environmental implications during the conduct of military operations. Much is written about the practice of environmentally sound and sustainable waste management practices within barracks, garrison or exercise settings, but much less consideration has been given to these issues for deployed forces in operations.

Worldwide the waste management function is dealing with a considerable rise in environmental and legal standards; best practices; occupational health and safety; quality management; and the need for increased efficiency. Deployed military forces are not immune from these influences but must also contend with the situation where invariably limited host nation waste management capability and related infrastructure is available to support often dispersed and mobile force elements.

Largely through a series of desktop studies, the report addresses the following science and technology requirements for deployed force waste management sought by DGLD:

- Functional Requirements – drawn from legislative/regulatory requirements, best practice advice provided from environmental authorities and waste management operators, and publicly available scientific and technical information, a broad picture of possible deployed force waste management functionality is presented.

- Research and Development – a brief overview is provided of Australian research and development in waste management and related areas.

- Technology Review – a range of mechanical, chemical, biological and thermal waste treatment and disposal technologies are reviewed with reference to a number of criteria.

- Waste Management Modelling – an examination is conducted of potential mathematical models and tools to support deployed force waste management analysis.

The work described in this report is the first examination by Land Operations Division into deployed force waste management. As such it provides a useful step in informing the capability development process and provides a number of pointers to where science and technology may add value.

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1. Introduction

1.1 Background

Over the closing decades of the last century and leading into current times there has been increasing pressure to reduce and better manage waste, driven by community demand, government expectation and industry initiatives. In this regard, the growing demand to be proactive in providing effective, efficient and sufficient waste management systems extends to deploying military forces as evidenced by the drafting/promulgation of NATO and ABCA standards in this area and the consideration of deployable military capability solutions.

The waste management difficulties faced by deployed military forces, and the need for deliberate action in this area to safeguard against emergent health concerns and legacy environmental issues, are highlighted by studies of war related damage and environmental impact undertaken by the UN Environment Program (UNEP). Driven in large part by the nature of military operations and the circumstances in which deployed forces are called to operate, UNEP and other investigations often show that deployed forces have to contend with poor levels of host nation infrastructure while, perhaps unsurprisingly, their combative actions exacerbate pre-existing waste management problems[1],[2],[3]. In deciding how best to manage such a problem the claims such as those made by the International Solid Waste Association (ISWA) concerning civil experience can be instructive. The ISWA reports that, in the US today, more money is spent on dealing with past pollution than on managing the current treatment and disposal of hazardous waste, even though the quantities of newly generated waste are greater[4].

Motivated by the ADF's recent operational experiences and set against this backdrop of rising concerns for reducing and better managing waste, the Director General Land Development (DGLD) commissioned effort to investigate waste management capabilities required by deployed military forces. The work described in this report is part of that effort.

1.2 Aim and Scope

The aim of this report is to examine a range of science and technology issues concerning waste management for a deployed military force.

The work incorporated in this report was largely produced through a series of desktop studies. Drawing largely from publicly available information and material gained from industry conferences, and combined with a range of verbal inquiries and discussions with industry, academia and military units the report brings together a number of key parts to

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[1] United Nations Environmental Program, (2003) Post Conflict Environmental Assessment – Afghanistan

[2] United Nations Environmental Program, (2003). Desk Top Study on the Environment in Iraq

[3] Daglish P., (2004). Water Supply and Sewerage Strategic Planning – An Iraqi Experience in Proceedings of Enviro 04, Sydney 28 March – 1 April 2004

[4] International Solid Waste Association (2002), Industry as a partner for sustainable development – Waste Management

the deployed force waste management capability. A full list of source documents is contained in Section 8, References.

1.3 Report Overview

This report is divided into a number of sections, each one addressing an individual science and technology requirement sought by DGLD. The report begins in Section 2 by briefly providing scene setting information, outlining some core waste management concepts and relating contemporary military and commercial experience concerning waste management. Section 3 introduces the waste management functions that a deployed force may need performed and starts to articulate the range and depth of requirements for a deployed force waste management system. In Section 4 a brief overview of waste management and related research and development undertaken in Australia is provided, and a qualitative assessment of waste management treatment and disposal technology is provided in Section 5. Section 6 details an examination of potential mathematical models and tools that could support the analysis of deployed force waste management.

2. Context for Deployed Force Waste Management

2.1 Introduction

The deployment of a military force requires a range of planning activities. At some point in these activities, the need will arise to consider how best to deal with the significant quantities of waste that are produced as a result of operations[5]:

> 'Sound waste management plays an important role in the successful prosecution of ADF objectives. It is paramount that waste is managed effectively as a force health protection measure. Throughout history there are numerous examples of illness and disease impacting significantly on military operations. Poor management of waste can directly influence force health by creating environments suitable for the proliferation of disease carrying vectors.
>
> The ADF is also required to comply with a range of international agreements, conventions and Australian Legislation that relate to the protection of the environment. This governance framework places great emphasis on the responsible management of waste by a deployed ADF force. There is also a 'hearts and minds' aspect to waste management – particularly for conflicts at the lower end of the spectrum of war. Managing waste effectively will ensure that the local populace is not faced with an environmental clean up legacy courtesy of the ADF. The costs of such rectification are significant and depending on the nature of the problem, could be orders of magnitude larger than the funding required to implement a robust waste management system.'

[5] Fidge A., (2002). The Management of Waste For a Deployed Force, Paper presented to the Land Warfare Conference 2002

In this section some core waste management concepts are introduced and contemporary military and commercial experience concerning waste management is outlined.

2.2 Core Concepts

2.2.1 Waste Streams

When considering the management of waste it is common to conduct analysis with respect to a number of sub-divisions. Waste within these sub-divisions or streams has common characteristics and these characteristics provide a means of determining collection, distribution, treatment and disposal pathways. A common waste stream structure is:

- Solid Putrescible waste (mainly food scraps),
- Solid Inert waste (i.e. non-biodegradable and non-hazardous),
- Grey Water (mainly from washing activities),
- Black Water (toilet waste),
- Gaseous waste (inert, hydrocarbons and others),
- Biomedical waste, and
- Hazardous waste.

2.2.2 Waste Management Hierarchy

Waste management should be based on a hierarchy of waste management practices and these are:

- Waste avoidance – practices that prevent the generation of waste altogether;

- Waste minimisation – practices that reduce waste or enable direct reuse of waste materials for the same grade of use;

- Waste recycling or reclamation – practices that enable the use of valuable components of waste in other processes;

- Waste treatment – practices that reduce hazard or nuisance inherent in waste, preferably where generated; and

- Waste disposal.

Commonly, waste is best avoided or reduced at the point of generation, but in some instances strategies can be used to reuse and recycle wastes that are generated. Inevitably some waste will need to be treated and disposed.

In the deployed force setting treatment and disposal represent the immediate tactical problem, while individual units have some ability to reuse waste materials and minimise waste generation. Operational level decisions can influence waste minimisation through such things as rationing and water distribution plans, while waste avoidance is most directly influenced by strategic level decisions that relate to such matters as packaging and product substitution.

2.3 URS Study

In 2002 DGLD commissioned URS Australia to undertake a study of the waste management requirements of a deployed ADF force[6]. The main part of the study sought to gain an understanding of the waste stream created by a deployed force, to undertake a review of appropriate waste management technologies and to recommend broad waste management capability options.

The work contained in this DSTO report attempts to complement the URS study. A number of new issues are considered and a broader context taken up. In particular, the DSTO work has attempted to consider waste management across the full spectrum of operations including the considerable waste streams generated by use of munitions, manoeuvre and occupying ground within a conventional setting.

2.4 Contemporary ADF Experience

A deployed force may be faced with:

- A lack of fixed infrastructure to support waste management activities;

- It is likely to be spread over significant distances;

- The task of waste management is competing for resources against important operational imperatives;

- Enemy interdiction can interrupt waste management activities; and

- In most situations, the deployed force is subject to the same range of legal requirements as a garrison-based force.

Within the context of ADF deployed forces, responsibilities for waste management are spread across the logistics, engineering, health, legal and civilian military cooperation (CIMIC) domains. Adding to this divided responsibility is the observation from past operations that waste management holds a weak position in the context of other deployed force services[7]. Rather than implementing comprehensive waste management capabilities (from Unit to Force level) and deploying appropriate prepared force element packages, the ADF has largely risk managed the issue. As a result ad hoc arrangements for waste management tend to emerge as operations progress much as implemented in East Timor[8]:

> 'This led to some of the problems associated with waste management that were evident during the initial stages of ADF operations in East Timor during OPERATION WARDEN. East Timor's existing waste management facilities were in poor condition. There were limitations in the capacity of the sewerage system, and grey water treatment facilities were non-existent. There was an existing landfill that

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[6] URS Australia Pty Ltd, (2002). A Study into ADF Waste Management for Deployed Forces

[7] A view reinforced in discussions with ADF engineering and logistic personnel.

[8] Land Development Branch, (2003). Findings of 'Waste Management for Deployed ADF Forces on Operations' Industry Workshop

proved to be too small for the force's needs and was rapidly filled. As a result, there was a requirement for a number of landfills to be quickly constructed and subsequently decommissioned when their capacity was reached.

The ADF element of INTERFET was poorly prepared to execute its waste management responsibilities in East Timor. The force was not equipped with appropriate receptacles for the collection, storage and distribution of waste. This led to rapid acquisition of skips and transport vehicles. The management of sewerage was also problematic. Within Dili, the infrastructure could not handle the requirements of the deployed force. The initial use of field latrines gave way to the deployment of significant numbers of Portaloos. In turn, this necessitated the acquisition of a sullage truck to clear the Portaloos and transport raw sewerage to a location for final disposal. Some elements of hazardous waste were backloaded to Australia to be disposed of by third parties in accordance with extant ADF policy.'

Similar experiences have been reported for operations in Bougainville and the Solomon Islands.

Below the international and national environmental regulatory framework that deployed forces must comply with and the Department of Defence's strategic environmental objects, the ADF has a range of tactical level and single service doctrine and systems in place. However, perceived shortcomings in waste management outcomes continue to be highlighted during operations. The solution to these shortcomings need not necessarily lie with technology driven remedies as evidenced from the following assessment of the East Timor experience:[9]

'More complex factors including the failure of HQs to articulate and implement a robust waste management plan, units lack of consideration of MAP and the inability of the stretched logistic system to quickly respond when this was identified in country, contributed to the problems identified.

The move from Unit level responsibility for waste management to Formation and Force level has put a heavy burden on logistic assets and concentrated waste streams to a point where Formation and Force level assets are poorly equipped to deal with, and where volumes are difficult to manage.

This situation has arisen due to restrictions placed on waste management during exercises in Australia and Units, Formations and Force elements not practicing waste management in the field, leading to this aspect of campaigning being poorly implemented on deployment. The basic principles of Unit responsibility for waste management in order to minimise the load on the logistic system was not enforced.'

2.5 Other Approaches

This DSTO work was also keen to baseline, where possible, ADF deployed force waste management strategies with other military forces and comparable organizations.

[9] Brief for CO 2 HSB, Review of JP 2059 Related Projects – A Study into ADF Waste Management for Deployed Forces 17 Jun 02

2.5.1 Military Forces

It has been somewhat difficult to obtain detailed information concerning the deployed force waste management practices of other nations. The URS study reviewed a range of policies relevant to waste management from overseas authorities but these were largely broad, aspirational, strategic statements as opposed to detailed descriptions of military best practice, standards, procedural matters, or applied technologies.

The Canadian Forces did provide a copy of their draft aide-memoire for deployed force waste management[10]. This document outlines that Canadian Forces will strive to meet or exceed Canadian environmental laws, and, as much as possible in circumstances where the infrastructure has deteriorated, conform to host nation and international standards. This Canadian approach to deployed force waste management appears largely reliant on host nation support and 'come as you are' waste management capabilities. It presents the picture that pragmatic and field expedient methods for waste treatment and disposal will be employed as opposed to a task specific, well defined and deliberately constructed waste management system.

2.5.2 Non Military

ISWA makes some interesting observations about the differing approaches to waste management across the world. As with the ADF, it might be reasonable to expect that military forces reflect the national emphasis when it comes to health and environmental concerns during operations: [11]

- European Union – The member states of the European Union have reached the most advanced state in waste management in the world. Policy making in the field of waste management is primarily driven by environmental objectives. Economic considerations are mostly restricted to statements like 'economically reasonable' without concrete valuation. The resulting high-tech solutions are rather expensive. The final goal is in reducing landfilling to a minimum. The question of whether or not the environmental benefits outweigh the financial costs is hardly ever asked.

- The United States – Compared with the European Union, a more pragmatic approach is used in the United States. Economic considerations based on cost-benefit analysis play an important role in policy-making. Due to this approach, landfilling continues to be the most common solution in the United States. Two factors play an important role in this context; a relatively low population density, and incomplete cost accounting of waste management alternatives.

- Other high and medium income countries – Some high and medium income countries follow the approach of the European Union, some follow that of the United States. Limited availability of land normally leads to more European solutions (for example, Hong Kong, Singapore, Japan). Countries where this limitation does not exist tend to follow the pragmatic course of the United States.

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[10] National Defence Headquarters, (2004). Canadian Forces International Operations Best Practices Aide-Memoire for Waste Disposal Options

[11] International Solid Waste Association (2002), Industry as a partner for sustainable development – Waste Management

- Economically developing countries – Economically developing countries generally lack policies aimed at the management of solid wastes. In addition, most countries do not have modern regulations; existing regulations are antiquated and rarely enforced.

The work is this report also sought examples from other non-military domains that may have relevance to deployed military forces. In particular, the Australian Antarctic Division was investigated[12]:

> 'Until relatively recently, waste disposal practices in Antarctica were similar to elsewhere in the world with open tips, landfills and burning, as well as the practice of 'sea-icing' – dumping rubbish on the sea ice during winter to float away and sink during the summer. Sewerage was burned or else discharged with little or no treatment straight into the sea. Some areas around stations and field camps became contaminated from oil and chemical spills. Large amounts of packaging which could not be re-used or recycled, were also sent to Antarctica.'

As a result site remediation and research into the behaviour of contaminant in Antarctic conditions is now a focus of the Division's effort [13]. While a large part of the Division's strategy relies on repatriation of waste out of the field and back from camps to Australia, thermal (incineration) and biological sewage treatment technologies are also employed for some onsite treatment. Residual by-products (ash and sludge) from these latter processes are in turn repatriated to Australia.

Finally, local Government, particularly regional, rural and remote area authorities, perhaps provide another useful civil point of reference for deployed force waste management. In these settings communities have a large role to play, far greater than in municipal areas. They are also characterised by the following conditions[14]:

- Waste collection has major logistics and financial implications;
- Poor economies of scale exist;
- Small, dispersed populations;
- Small waste volumes;
- Limited collection services;
- Higher transport costs; and
- Poor data availability for planning purposes.

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[12] www.aad.gov.au

[13] Proceedings of the Third International Conference on Contaminants in Freezing Ground, Hobart 14-18 April 2002

[14] Skelt K., Povey N., (2004) Waste Policy in Rural Communities – The Balancing Act in Proceedings of Enviro 04, Sydney 28 March – 1 April 2004

2.6 Concluding Remark

The ADF can no doubt learn much from the past experiences of other organisations both within Australia and internationally when it comes to waste management. However, slowly but surely the waste management industry is moving away from a 'waste collection, recycling, treatment and disposal' paradigm and towards a 'resource reuse' paradigm that focuses on diverting waste away from disposal and maximizing the exploitation of raw product reverse logistics. This has implications for the industry's modus operandi; the types of capabilities organisations invest in, possess and can provide to the ADF; and the industry's cost and pricing structures. This emerging paradigm may not line up neatly with the ADF's deployed waste management needs.

3. Waste Management Functional Requirements

3.1 Introduction

This section contains an analysis of the functional requirements of a deployed force waste management system. This statement of requirements aids in the problem definition process and contributes to an overall systems and 'form follows function' approach to examining waste management for a deployed force. As such, it provides a basis for a requirements breakdown from which doctrinal, materiel and service solutions for deployed force waste management can be mapped. This analysis considers the key operational effectiveness or suitability issues that determine the waste management system's capability to perform its mission and outlines the key functions or activities that must be undertaken.

3.2 Higher Level Operational Issues

Waste management is not the core business of a deployed force, however, it has become increasingly important to consider environmental implications during the conduct of military operations[15]. While it is recognised that the environment cannot be fully protected at all times during military operations, a potentially destructive activity, there are many opportunities during deployment, movement, waiting and redeployment when good environmental stewardship is not only possible but also necessary.[16]

Worldwide the waste management function is dealing with a considerable rise in environmental and legal standards; best practices; the need for increased efficiency; quality management; and occupational health aspects[17]. Recent operational context for the ADF has seen forces operating in environments which have limited waste management capabilities often hosting such methods as uncontrolled dumping; on-site open burning;

[15] The ADF Future Joint Logistic Concept (April 2002) notes that environmental concerns will continue to exert pressure on military planners and logisticians and that the Australian public will expect the ADF to be environmentally responsible.
[16] Draft QSTAG 2044 – Hazardous Waste Management
[17] International Solid Waste Association (2002), Industry as a partner for sustainable development – Waste Management

insufficient and inefficient collection services; and scavenging of material from collection, treatment and disposal sites sometimes for the purposes of commercial resale.

Much is written about the practice of environmentally sound and sustainable waste management practices within barracks, garrison or exercise settings, but much less consideration has been given to deployed forces. The defining features of deployed forces with regard to waste management are that they are potentially dispersed, transient, mobile, self-reliant and subject to operationally induced interruptions.

A system of waste management for deployed forces must:

- Act as a force protection measure (facilitating prosecution of the operational mission) ensuring that the collection, distribution, treatment and disposal of waste is managed so as to not undermine the human health of the force. This includes approaches to reduce waste handling and storage.

- Enable a deployed force to comply with specified regulatory requirements, agreements, and conventions governing waste management and environmental protection. This includes compliance with local, national and international conditions.

- Allow the deployed force wide operation in an environmentally-independent manner. This includes reducing the reliance on supporting organisations and facilities.

- Ensure waste management operations do not compromise the combat effectiveness of the force.

- Minimise the need for environmental rectification and after care as a result of ADF operations.

- Provide a technically sound and resource efficient solution (in terms of time, infrastructure needs [e.g. power], manpower and through life costs).

- Provide a level of waste management both with, or in the absence of, domestic, host nation, contractor and coalition support (at least initially in an operation).

- Improve the perception of the deployed force in the domestic, host nation and international public forum as an integral part of a peace building process.

3.3 Functional Breakdown

A diagrammatic representation of the deployed force waste management functions is shown in Figure 1. Appendix A provides a short description of each of these functional elements and Appendix B describes elements and sub elements in detail. At the heart of waste management are a number of key functional areas:

- Collection and Distribution[18] – The management of the waste stream will generate a requirement to collect and distribute waste on the battlefield. This will be closely linked to the adopted treatment and disposal methods. However, it will not be possible to dispose of all wastes at its point of origin and the collection and distribution capability must be equipped with appropriate systems for the safe and efficient centralisation of waste.

- Treatment and Disposal – Treatment processes simplify disposal, by reducing the volume and/or the toxicity of waste and in some methods, and, for some waste streams, recyclable materials may be produced as by-products. However, at this stage, despite all efforts to reduce, recycle and treat waste, there will still be a need for disposal methods. Some waste treatment and disposal technologies are more suited to centralised management while others can efficiently treat waste at its point of origin.

- Waste Management Planning and Operations – Overlaying these execution components is the action of devising, implementing and coordinating a system of deployed waste collection, distribution, treatment and disposal. While the collection and distribution services may be regarded as requiring a logistics approach, by their nature the planning and operation of treatment and disposal services require a scientific/engineering approach. It is this function that ensures desirable outcomes are obtained for the high level operational issues described previously.

3.4 Conclusion

The description of the functional requirements of a deployed force waste management system is a necessary step in determining the full extent of capability needs and gaps. It shows that while collection, distribution, treatment and disposal are central to the system other management and oversight functions are required for system completeness.

[18] Land Development Branch, (2003). Findings of 'Waste Management for Deployed ADF Forces on Operations' Industry Workshop

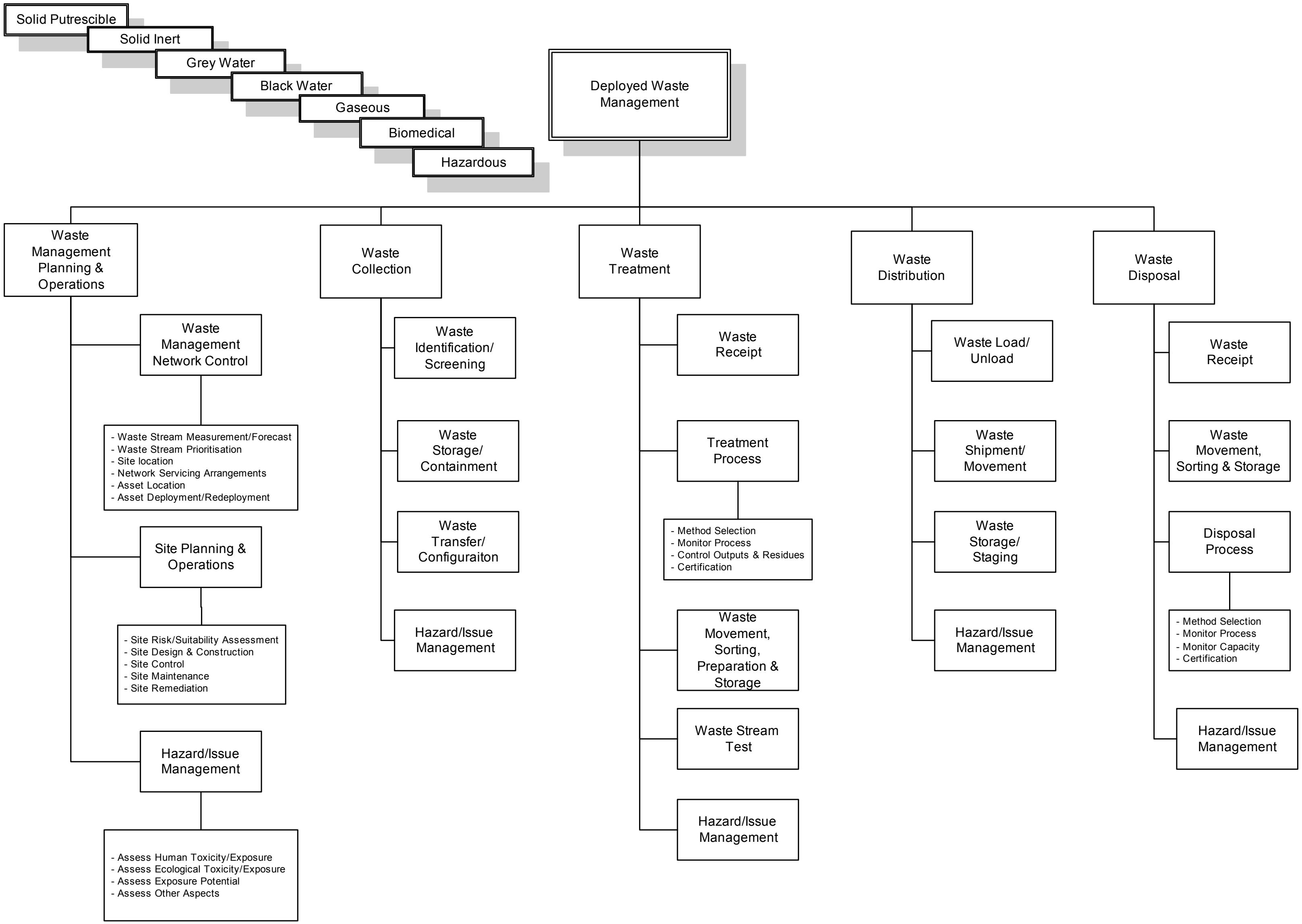

Figure 1 – Functional Analysis Diagram

4. Waste Management Research and Development

4.1 Introduction

The purpose of this section is to examine relevant industry and academic developments and research in the area of waste treatment and disposal technology. Information has been sought from the following areas:

- Annual reports and open source research summaries from Australian universities and collaborative research and development centres and programs.

- A range of Australian federal, state and local government sources along with a range of foreign government and international agencies/collectives.

- Prominent industry sources for treatment and disposal technology both local and international.

4.2 Australian Research

Focal points of academic research and development in waste management within Australian are resident in areas such as:

- The Cooperative Research Centre[19] (CRC) for Waste Management and Pollution Control incorporating program components concerning waste water treatment, solid waste management and contaminated site remediation and hazardous waste treatment;[20]

- The Environmental Biotechnology CRC;

- The CRC for Water Quality and Treatment incorporating program components concerning water treatment technologies;[21]

- University of NSW Centre for Water and Waste Technology which currently includes research programs in solid waste treatment, life cycle assessment and waste water treatment;

- University of NSW School of Biotechnology and Biomedical Sciences, and the School of Civil and Environmental Engineering;

- University of Queensland Advanced Wastewater Management Centre;

- Griffith University School of Environmental Engineering;

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[19] The CRC Program was established in 1990 to improve the effectiveness of Australian research and development effort. It aims to link researchers from universities, CSIRO and other government laboratories and private industry or public sector agencies to focus R&D efforts on progress towards utilisation and commercialisation.

[20] CRC for Waste Management and Pollution Control Annual Report 2003-2003

[21] CRC for Water Quality and Treatment Annual Report 2002-2003

- RMIT School of Civil and Chemical Engineering;
- University of Western Sydney Water Research Program;
- Murdoch University Centre for Organic Waste Management that has expertise in alternative, small-scale waste management systems applicable to developing and/or remote communities.

4.3 Cooperative Research Centres

The CRCs draw together many of the university research efforts where commercialisation or public good might be derived. As such they provide a reasonable pointer to where nearer term R&D might be leading to realisable waste management technology. The CRC for Waste Management and Pollution Control (CRCWMPC) is concluding its activities in the near future but has progressed a range of projects in the following areas:

- Waste Water Treatment and Water Reuse – Research and development (R&D) effort driven by the perceived needs of the waste water treatment industry to lower capital and operating costs, reduce energy demand, a preference for distributed treatment systems, increased use of treated wastewater, adding value to waste products and achieving higher environmental standards.
- Solid Waste Management – R&D effort driven by significant pressure to both reduce the community's dependence of landfills and to manage society's waste in a more sustainable way. Because of this driver, research has focused on innovative processes and equipment for the treatment or stabilization of waste and the coversion of waste to value added materials. Studies in advanced bioreactor landfill design (incorporating leachate recycling technology) have led to developments that significantly reduce 'start up' and gas generation times.
- Contaminated Site Remediation and Hazardous Waste Treatment – R&D effort focused on environmental monitoring technologies and advanced technologies for the destruction of hazardous substances, specifically chlorinated hydrocarbons.

Over the life of the CRCWMPC, facilitated through Waste Technologies of Australia Pty Ltd (the CRC's IP transfer or holding vehicle for commercialisation of CRC products), licensed technologies have been developed in:

- Electro-dewatering (EDW) - increasing the solid content of sewage sludge to at least 30%, and in some instances to more than 50%, offering efficiencies in distribution costs for the disposal or reuse of sludge.
- UniFED™ - a low cost system for the removal of biological nutrients from wastewater.
- Multiple Water Reuse (MWR) – for in situ, on demand, reuse of wastewater using membrane filtration.
- Diffusion Cell technology – for on-line, real-time detection of pollutants.

- MSAT Biosensor – a luciferase-based[22] biosensor that can be modified to detect a wide range of contaminants.

- SurePure™ – technology for the production of ultra pure water incorporating ion exchanges that require no acids or alkalis to regenerate ion exchange resins.

- HiRAT – an anaerobic process control system for use in sewage waste water treatment plants.

- Iron-based photo-oxidation process for quick and cheap removal of arsenic from drinking water and ground water.

The CRCWMPC also progressed a 'public good' project to test and promote SKYJUICE, a small, simple portable low cost device useful for treating water. The device was seen to be useful to remote communities with only contaminated water supplies or where a disaster has affected the quality of water available. Bushwalkers, for example, may be able to apply this technology. US military forces have apparently shown some interest in this technology.

To some extent the Environmental Biotechnology CRC (EB CRC), opened in late 2003, follows on from the CRCWMPC. With regard to waste management, and as its name implies, the EB CRC focuses on biological as opposed to physical and physical-chemical processes. Many of the current bioprocesses fundamental to waste management technologies are relatively inefficient and ineffective. This CRC has research programs in cellular and microbial community processes, bioprocess operation and bioprocess engineering that include current projects concerning rapid waste digestion systems, novel biofilm control strategies and coatings applicable to solid-liquid interfaces (such as in sewerage systems or water pipes), bioremediation strategies and processes for highly contaminated environments, and rapid detection strategies for pathogens in waste and wastewater systems.[23]

The CRC for Water Quality and Treatment in its Water Treatment Technology program seeks to identify and/or develop improved engineering and system management of treatment processes for control of problem organisms and compounds. Technology transfer in the case of this CRC appears to be focused on direct involvement of industry in research projects, publication of scientific outcomes and workshop activities directed at parties or associates of the Centre. In the Water Treatment Technology program priority areas of research are:

- Combined treatment processes for natural organic matter;

- Effect of UV on bacteria/viruses/protozoa and remainder of treatment processes and distribution systems;

- Biodegradation of taste and odour compounds, and microalgal toxins;

- Biological reactors for removal of natural organic matter;

[22] A bacterial enzyme involved in bioluminescence
[23] Environmental Biotechnology CRC Seven Year Business Plan, 29 May 2002

- Optimisation of treatment and disinfection processes for destruction of key pathogens; and

- Biological manganese removal.

4.4 Conclusion

Through these types of R&D efforts Australia takes a lead role in environmental stewardship. As such, these centres of waste management research potentially provide a rich source of cutting-edge information and largely commercially independent advice for the ADF waste management capability as it is formed and developed.

5. Waste Management Technology

5.1 Introduction

The URS Australia study examined a range of treatment and disposal technologies. Many of the technologies examined in this report are described within the URS report so no attempt has been made to further describe them here[24]. The New South Wales Government inquiry into Alternative Waste Management Technologies and Practices[25] also contains explanations of some of the technology options considered here. The emphasis here is to complement the URS Australia study.

5.2 Technology

Through this work the following groups of treatment and disposal technologies and systems were assessed in relation to deployed force waste management:

- Thermal Treatments – utilise heat for the destruction and/or treatment of waste.

- Chemical Treatments – utilise neutralisation or chemical separation to treat waste.

- Mechanical Treatments – includes actions such as shredding, grinding and sorting that seek to render some materials suitable for recycling or reduce the volume of material requiring disposal.

- Biological Treatments – utilise micro-organisms to break down the organic contaminants of waste and convert them to usable or benign compounds.

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[24] URS Australia Pty Ltd, (2002). A Study into ADF Waste Management for Deployed Forces

[25] State Government of New South Wales (2000), Report of the Alternative Waste Management Technologies and Practices Inquiry

5.3 Assessment

Appendix C contains a qualitative assessment of selected technologies made against a number of criteria:

- Availability – the ease with which the technology can be obtained and the extent to which it is fielded/employed in the wider waste management sector.
- Deployability – the ease with which the technology can be moved to and within a theatre of operations.
- Specialised Equipment – the extent to which specialised equipment is inherent in the technology either through construction or operation.
- Personnel – the personnel skill requirement to commission and operate the technology.
- Cost – the relative acquisition and through life cost of the technology.
- Suitability – a general assessment of the appropriateness of the technology from operational, environmental, social and economic perspectives.

5.4 Conclusion

After considering this assessment of technologies three key points emerge:

- Technology solutions for liquid waste management (such as grey and black water treatment) in a deployed setting seem reasonably accessible. That is, there are known technologies, capable of modularisation that could be deployed with ADF elements.

- The situation for solid waste management is less clear. If we start from the position that the application of waste management technology in a deployed setting must meet the environmental expectations of the Australian regulators and community then it is clear that a range of 'alternative' technologies are yet to pass muster. Specifically thermal technologies such as gasification and pyrolysis that are seen as closely aligned with incineration methods are yet to be widely accepted at a social and political level. Given this, even if the ADF were to pursue these types of technologies the user base in Australia is likely to be small and perhaps lead to off-shore acquisition and support. In addition, while landfill will have a place in the waste disposal system for some time to come it is seen as 'stone age' technology that is unsustainable as a core component of any waste management strategy. All these factors potentially muddy the technology space for deployed force solid waste management.

- The importance of knowing the deployed force waste stream characteristics cannot be overstated. This includes knowing whether the stream may or does change over time. Technology solutions adopted need to be able to match up to the waste stream and be flexible/adaptable should or when the stream changes, alters or fluctuates.

6. Waste Management Modelling

6.1 Introduction

The purpose of this section is to examine potential mathematical models and tools to support waste management analysis. Much of the information contained in this section has been drawn from a range of technical and scientific journals and reports related to waste management, environmental science/engineering and operations analysis. Representative articles are detailed in Appendix D and grouped according to their principal area of emphasis. Additionally, Appendix E demonstrates some waste management modelling results modified from a NSW State Government Inquiry concerning alternative waste management technologies. **The numbers appearing in parentheses throughout this section refer to documents described in Appendix D**.

The literature suggests there is no turnkey solution to waste management modelling and different approaches to *ab initio* modelling may have varying levels of complexity, resource intensiveness and utility. This point would appear even more applicable to the military setting given that the information sourced for this annex principally related to civil or commercial situations, and no evidence could be located of waste management modelling for deployed military forces. However, the appropriate modelling approach is largely dependent on the issues to be resolved and the decision making processes to be informed. Other factors such as the practical difficulties of assembling the necessary data sets, determining the level of complexity and detail required, and the computational efficiency desired also need to be considered.

6.2 Determining the Problem to be Addressed through Modelling

Any program of analysis needs to focus on the problem solving aspects rather than the model creation or adoption. In the deployed force setting, it is clear that various stakeholders will have various 'problem perspectives' from which to assess a waste management system:

- Commanders will be concerned with the overall force effectiveness and how waste management issues affect it.
- Environmental health authorities will be concerned with the human health impacts of waste management activities.
- Engineering and technical authorities will be principally concerned with the effective and efficient planning, design, construction, commissioning, operation and decommissioning of waste treatment and disposal infrastructure.
- Logistic authorities will be principally concerned with the effective and efficient collection and distribution of waste materials for treatment and disposal.
- Units will be concerned with how the deployed force waste management strategy meets the waste needs within their respective organisations without detriment to primary mission requirements.

Stakeholders at the strategic, operational and tactical levels of the force and ADO will also have differing problem perspectives. With these varying perspectives in mind the types of problems to be addressed by waste management modelling might include the following:

- Determine the need for deployed force waste management through the characterisation and estimation of waste stream mass, volume and peak flow.
- Assess the impacts of alternative waste management technologies, policies and practices.
- Select appropriate waste management system component technologies, policies and practices.
- Determine an optimal mix and allocation of selected resources in a waste management system.
- Estimate the expected performance level of a selected waste management system over time.

The following paragraphs address modelling approaches to these problems. In using the term 'modelling', the 'model' element is used in its most general sense and is taken to mean a representation of a system, component, process or phenomena. A model may be explicitly displayed as a physical, graphical, mathematical, text-based etc. representation or perhaps some combination of these. The waste management models in this section are principally founded on mathematical representations or techniques.

6.3 Characterising and Estimating Waste Streams

Modelling of alternative waste management systems can be undertaken with reference to the mass and/or volume of waste streams as they pass within and through a system. Haith [1] describes a spreadsheet based model that produces waste generation estimates for 50 different waste products and tracks their disposition through a waste management system consisting of source reduction, recovery (recycling and composting), waste-to-energy combustion and landfilling. Haith describes this type of accounting approach in the context of assessing management decisions concerning the physical scale and productive outputs of a municipal solid-waste system. Typical outputs from the model include the mass and volume of waste generated, collected and diverted by source reduction or recovery; physical scale (daily mass and/or volume) of facilities; landfilled mass and associated volume requirement; potential annual landfill gas production; and net electrical power production for the combustion facility. In Haith's approach waste generation is determined based on per capita rates for specific waste types and a range of density data sets are used to determine volumetric requirements for matters such as collection and landfill.

6.4 Assessment of Waste Management System Impacts

This area of modelling focuses on the environmental effects of waste management, principally through examining emission rates of different technologies and practices, and in some instances balancing these factors against others such as the economic cost of operation. This type of modelling often requires an understanding of processes in the physical sciences that lie at the heart of various waste management technologies and practices.

Examples of this type of modelling [2]-[4] include examination of emissions arising from treatment of specific waste streams such as medical or hazardous waste; examination of emissions arising from different waste management treatment options such as incineration, resource recovery, biological and landfilling; and hydrologic evaluation of landfill performances for the consideration of landfill design alternatives.

In a similar vein, Life Cycle Assessment (AS/NZS ISO 14040:1998, [5]) is a technique for assessing the environmental aspects and potential impacts throughout a product's life from raw material acquisition through production, use and final disposal. While most life cycle studies have been comparative assessments of substitutable products delivering similar functions (e.g. glass versus plastic for containers), more recently there has been a trend towards the use of life cycle approaches in comparing alternative production processes and this includes the use of LCA in comparing waste management strategies.

6.5 Assessment of Waste Management System Cost Benefit

These types of models [6] enable decision makers to assess the effects of a waste management strategy by translating all impacts into a common measurement, usually monetary. This means that impacts which do not have a monetary value, such as environmental impacts, must be estimated in monetary terms. There are several ways to do this, such as estimating the costs of avoiding a negative effect (eg the cost of pollution control on an incinerator) or establishing how much individuals are willing to pay for an environmental improvement. For a civil application, social impacts can also be evaluated in the same way.

6.6 Multi-Criteria Assessment of Waste Management Technologies and Systems

A particularly prominent approach in waste management modelling is the application of multi-criteria decision making [7]-[15]. This multi-criteria assessment establishes preferences between options by reference to an explicit set of objectives that a decision making body has identified, and for which it has established measurable criteria to assess the extent to which each objective has been achieved. In simple circumstances, the process of identifying objectives and criteria may alone provide enough information for decision makers. However, multi-criteria assessment offers a number of ways of aggregating the data on individual criteria to provide indicators of the overall performance of options.

A key feature of multi-criteria assessment is its emphasis on the judgement of the decision making team in establishing objectives and criteria, estimating relative importance weights and, to some extent, judging the contribution of each option to each performance criterion. All multi-criteria assessment approaches make the options and their contribution to the different criteria explicit, and all require the exercise of judgement. They differ however in the arithmetic procedures used to combine the data.

There would appear to be a fairly consistent group of higher-level objectives and criteria sets upon which waste management strategies, concepts, technologies etc. have been assessed in the literature. Hokkanen et al [11] provided a survey of the more common objectives and criteria used in multi-criteria assessment for waste management systems (applicable in civil and commercial situations):

- Economic
    - Capital cost
    - Operating cost
    - Revenues
    - Net cost per ton

    - Net annual cost per household
    - Financing arrangements
- Technical
    - Feasibility
    - Operating experience
    - Adaptability to local conditions
    - Reliability
    - Continuous
    - Uninterrupted process
    - Potential for future development
- Environmental
    - Global
        - Greenhouse effects
    - Regional
        - Release of acidificative compounds
        - Surface water dispersed releases
        - Releases to the air and water with health effects
    - Local
        - Environmental hygiene
        - Surface water dispersed releases
        - Releases to air and water with health effects
- Political/Social
    - Public acceptance
- Employment
    - Number of employees
- Resource recovery
    - Products recovered
    - Energy requirements – net effect on primary energy supply
    - Market potential
    - Land usage – volume reduction

Appendix E provides an example of this type of analysis applied to alternative waste management technologies. This appendix is based on an inquiry undertaken by New South Wales government authorities into alternative waste management technologies and has been amended where possible to reflect potential deployed force emphasis.

Morrissey [7] outlines the benefits and limitations of this type of multi-criteria modelling:

- It allows a systematic approach to evaluate policy options and helps understanding of the problem.
- A mixture of quantitative and qualitative information can be incorporated.
- Account can be taken of the preferences of various stakeholder groups with conflicting objectives.
- Multi-criteria techniques offer a level of flexibility and inclusiveness that purely economic based models tend to lack.
- These methods do not produce the best solution but a set of preferred solutions or a general ranking of all solutions. Solving a multi-criteria problem is, therefore, a compromise and depends on the circumstances in which the decision aiding process is taking place.
- There is a need for personal judgement and experience in making the decisions
- Some of the multi-criteria techniques are very cumbersome and unwieldy.

- The allocation of weights to each criterion is subjective. Changing the weights could lead to a different result.
- When this category of model is used to consider waste management options, the models identified in the literature take into account waste once generated only. Waste prevention, waste minimisation, or product design for the environment, which would eliminate the production of materials that cannot be reused, recycled or naturally biodegraded are generally not considered.

6.7 Planning and Allocating Resources in a Waste Management System

Other approaches to waste management modelling incorporate the objective of finding an optimal arrangement of resources in a waste management system. In the literature these are invariably presented as network or trans-shipment optimisation models [16]-[23], that consider issues such as the scheduling and routing of waste collection services and/or the placement and capacity requirements of treatment and disposal facilities. For these models the waste management system is often described as a network of connected nodes, where nodes represent either a waste source or a place of collection, treatment or disposal, and the nodes are connected by some mode/(s) of transportation. In general these models are highly scenario dependent and most applicable when there are a large number of connected nodes in the waste management network.

Conceptually, a model of this type [16] in a civil or commercial setting might seek to devise a system of waste collection, processing, treatment and conversion, and disposal that:

Minimises the net cost of operating a waste management system, where net costs includes elements for:
- transportation,
- waste processing, treatment and disposal operations, and
- revenue generated from recycling, resource recovery or conversion to energy.

Subject to meeting a range of requirements (constraints):
- the capacity of processing sites cannot be exceeded,
- the capacity of treatment and conversion sites cannot be exceeded,
- the capacity of disposal sites cannot be exceeded,
- the capacity of the collection assets cannot be exceeded, and
- mass outputs and byproducts arising from processing, treatment or disposal sites cannot be inconsistent with waste inputs to these sites[26].

In the previous sections dealing with assessment methods, approaches were presented that consider the environmental, economic, technical etc. impacts of specified waste management systems so that decision makers can make informed evaluations. Decision makers using only these assessment methods can only obtain the best system from among the waste management options that they were able to think of. However, the best waste management option might be a combination that was not thought of, and thus may not be examined by an assessment method. Conversely, optimisation methods comprise an approach to obtain the best waste management solution whether predetermined or not (albeit from within a constructed and constrained solution space).

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[26] Technically referred to as 'mass balance constraints'.

6.8 Simulating Waste Management System Performance

Perhaps somewhat surprisingly, only limited evidence could be found in the literature of the use of simulation in modelling waste management systems [24]-[26]. Such an approach could involve the use of discrete event simulation to model a network of waste management activity in much the same way as was undertaken by Land Operations Division for Joint Project 126 (Joint Theatre Distribution)[27]. At the heart of this type of modelling is a relatively detailed understanding of how deployed force waste management processes would be undertaken and the entities, objects or agents involved. In this process centric approach the types of issues that could be investigated for a deployed waste management system are:

- The number, location and dispersion of collection points, treatment and disposal sites for a deployed force;
- The number, capacity and other performance characteristics of collection (receptacles) and distribution (movement and handling) assets;
- Waste segregation policies;
- Servicing policies for collection points, treatment and disposal sites (eg collection frequencies)
- Employment of waste compaction systems;
- Throughput, capacity and other performance characteristics of collection, treatment and disposal sites;
- Priority systems for waste management; and
- Quarantine regulations.

A key purpose of applying discrete event simulation is to view the dynamic performance (or performance over time) of a deployed force waste management system.

This type of modelling is commonly scenario based and requires a reasonably detailed understanding of the operations and business rules of deployed waste management in order to develop the underlying process model. Data requirements in this type of approach can also be significant and often lie at the heart of the success or otherwise of such methods. In general, it can be a very quantitative approach that may have greatest application in later stages of the capability development process.

6.9 Generation of Waste Management Strategies and Concepts

Other more qualitative approaches focusing on logical representation of key factors in deployed force waste management may assist with the development of general waste management strategies and concepts. These types of approaches would work with less certainty concerning scenario factors and help determine <u>what</u> generic waste management capabilities might be required. Other methods discussed earlier would help to determine <u>how well</u> the system must perform and <u>which conditions</u> the system must perform in.

Deriving a full set of considerations or ‘drivers’ that challenge deployed waste management activities could be abstracted with reference to the Australian Illustrative Planning Scenarios. Likely permutations of these drivers might then be formed for the

[27] This work is described in DSTO Task ARM 01/058, Army Support Force Capability Studies.

development of alternative concepts of operations and identification of capabilities to enable them. For example, key considerations might include the following:

- Operational type – indicating likely threat levels,
- Operational scale – size and nature of forces,
- Intensity – indicating tempo of operations,
- Terrain,
- Mobility of force,
- Dispersion of force,
- Climatic Conditions,
- Time-frame/Duration,
- Local infrastructure - waste management, and
- Local infrastructure - enabling components (roads, buildings, utilities etc).

There is probably an ideal number of key considerations (maybe in the range of 5-7), permutations of which would cover the deployed force waste management problem space. Indicative settings and cursory analysis of the effects on capability requirements are set out in Table 1 as an example only.

Each effect would need to be tied to a factor variant by general capability, force package, or waste management system design rules. For example:

Factor: Local Infrastructure – Waste Management

Variant: Poor

Effect: Affects breadth and depth of waste management capability required within the force.

Capability/Force Package/System Design Rules: Requires consideration of:

- Force elements should attempt to work at the primary end of the waste hierarchy (avoidance, re-use, recycle, recovery of energy) as much as possible.
- Force elements should have the ability to independently meet their own waste management requirements for at least x days at unit and sub-unit level.[28]
- Rapidly deployable/re-deployable waste management assets should be available within y days.[29]
- The force has the capability to appropriately site waste management functions.
- The force has the capability to construct, set to work, and maintain waste management sites.
- The force has the capability to establish environmental baselines, monitor waste management functions and measure environmental impacts.

[28] Where 'x' is a derived planning figure
[29] Wher 'y' is a derived planning figure

Table 1 – Factor Settings

Factor	Likely variants	Effects
Operational Type	Warfighting Operations OOTCW – Peace Operations OOTCW – Support Operations	Affects the nature and likely scope of the waste management mission Affects the force's ability to employ commercial sources for waste management
Operational Scale	Large (national mobilization) Medium (multiple JTFs) Small (single JTF)	Affects the size of the waste management function
Intensity	High (continuous) Medium (frequent) Low (occasional)	Affects the waste management servicing arrangements within a deployed force
Terrain	Rugged Rolling Foothills/Hills Flat Rolling Dunes Swamp Urban	Affects the practicality of particular waste collection, distribution, treatment and disposal methods
Mobility of Force	High Low	Affects the ability to use fixed, centrally sited assets. High mobility potentially emphasises the use of field expedient devices designed for short term use, unit level management of waste etc High mobility potentially emphasises collection and distribution whereas low mobility emphasises treatment and disposal close to source
Dispersion of Force	Widely dispersed Dispersed (with some aggregation of forces down to formation level) Largely centralised	Affects waste management network design
Climatic Conditions[30]	Hot Dry (A1) (A2) Wet (B1) (B2) Hot Humid Coastal Desert (B3) Cold (C0) (C1) (C2) Severe & Extreme Cold (C3) (C4)	Affects effectiveness and efficiency of particular treatment and disposal technologies
Time-frame/Duration	Immediate (< 1 month) Short (1-6 months) Medium-Long (> 6 months)	Affects sustainability of force waste management function Affects benefits of adopting commercial sources
Local Infrastructure - Waste Management	Poor Fair Good	Affects breadth and depth of waste management capability required within the force
Local Infrastructure – Enabling components	Poor Fair Good	Affects waste management asset technical characteristics, network design and servicing arrangements

[30] Department of Defence (1986), Australian Defence Standard DEF(AUST) 5168, The Climatic Environmental Conditions Affecting the Design of Military Materiel - believed to be currently under revision.

In this method some combinations of factors and variants may potentially be highly improbable, and therefore a smaller number of cases only need to be considered. Consideration of the effects for the collection of factors and variants could then be developed into a broad waste management concept that points to capability requirements. So for example, consideration of the effects and collected capability rules would allow an outline concept to be developed for:

Operational Type	Warfighting Operation
Operational Scale	Medium (multiple JTFs)
Intensity	Medium (frequent ops)
Terrain	Urban
Mobility of Force	High
Dispersion of Force	Dispersed
Climatic Conditions	Cold
Time-frame	Short
Local Infrastructure - Waste Management	Moderate
Local Infrastructure – Enabling components	Moderate

6.10 Modelling Options

This section has considered seven broad approaches to waste management modelling:

- Spreadsheet based modelling for characterising and estimating waste streams,
- Specialised modelling of environmental effects of waste management systems,
- Assessment of waste management systems according to a cost benefit base,
- Multi-criteria assessment of waste management technologies and systems,
- Optimisation modelling to plan and allocate resources in a waste management system,
- Simulation of waste management system performance, and
- Option and strategy generation for waste management systems.

The method or methods adopted should largely depend on the nature of the problem to be addressed. Other factors such as the practical difficulties of assembling the necessary data sets, determining the level of complexity and detailed required, and the computational efficiency desired also need to be considered. However, the modelling approaches detailed in this section are consistent with the components identified by MacDonald in her design of a comprehensive decision support system for solid waste planning [29].

On the basis of the information presented in this section it is considered the following modelling approaches are achievable:

Short Term

- Multi-criteria decision analysis to assist with the assessment of waste management capability options, using scenario independent criteria.
- Simple spreadsheet modelling to assist with scenario based:
    - estimation of waste stream quantities and composition;

  - aggregate level planning of waste collection, distribution, treatment and disposal requirements.

Near Term

- Modelling of the environmental impact of selected technology or processes, feeding this back into the multi-criteria decision analysis.
- Multi-criteria decision analysis to assist with the assessment of waste management capability options, using both scenario dependent and scenario independent criteria.
- Development of a waste management strategy and concept generator.

Longer Term

- Scenario based discrete event simulation of deployed force waste management.

7. Conclusions

Deployed military forces no doubt have a difficult task in managing waste in a theatre of operations. The issue struggles to compete with operational priorities, the circumstances in which action needs to be undertaken can be harsh and the quantities of waste that need to be dealt with can be potentially very large. This report has examined a number of science and technology issues relevant to this context and brought to light:

- The range and depth of deployed force waste management functions that must be either conducted by forces, for forces or on behalf of forces.

- A number of R&D centres of excellence within Australia that potentially could assist the ADF in developing waste management capabilities.

- The range of technologies available for deployed forces to deal with most elements of the waste stream. Of the general classes of solid, liquid and hazardous waste it is least obvious what is the most practical solution for solid waste management for deployed forces.

- A range of options available for modelling waste management that may assist decision making concerning the most appropriate system for deployed ADF forces.

The report also notes, however, that solutions to current capability gaps in ADF deployed force waste management need not necessarily lie solely with technology driven remedies. Sound tactics, techniques and procedures, and prudent operational and strategic level decisions can play their part in easing the burden for deployed force waste management.

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Appendix A: Functional Requirements – Short Description

A brief description of each of the deployed force waste management functional elements is contained in Table 2.

Table 2 – Waste Management Functional Requirements

Functional Breakdown Element			Description/Comment
Waste Management Planning & Operations	Waste Management Network Control	Waste Stream Measurement/Forecast	Measure, evaluate and forecast waste streams and waste stream components
		Waste Stream Prioritisation	Determine waste streams requiring priority for deployed force management and resource application
		Site Location	Determine temporary and permanent siting of waste management operations
		Network Servicing Arrangements	Determine arrangements for the flow of waste through the waste management network and the assignement of waste management functions and responsibilities within and for the deployed force.
		Asset Location	Determine allocation of assets within waste management network
		Asset Deployment/Redeployment	Deploy/redeploy assets within the waste management network
	Site Planning & Operations	Site Risk/Suitability Assessment	Conduct assessment of individual sites regarding the risk or suitability of conducting waste management operations
		Site Design and Construction	Design, prepare and construct waste management sites
		Site Control	Control site operations for each waste stream (includes Site security, safety and inspections)
		Site Maintenance	Control site maintenance, performance improvements and other engineering operations
		Site Remediation	Plan, prepare for and complete site restoration, after-care and closure

Functional Breakdown Element			Description/Comment
Waste Management Planning & Operations (cont.)	Hazard/Issue Management	Assess Human Toxicity/Exposure	Assess acute or chronic toxicity and exposure to humans
		Assess Ecological Toxicity/Exposure	Assess acute or chronic toxicity and exposure to organisms, species and plants
		Assess Exposure Potential	Assess factors such as bioaccumulation, bioconcentration, biotransfer, hydrolysis, nitrification, mobility, waste physico-chemical properties (eg flammability), emissions, occupational exposure
		Assess Operational Aspects	Assess impact of waste management operations on combat effectiveness of deployed force
		Assess Other Aspects	Assess issues such as human health, environmental impacts, nuisance (noise, smell, dust, loss of visual amenity, litter, pests, plagues), biodiversity, aesthetic value, regulatory interests
Waste Collection	Waste Identification/Screening		Identify, mark, document, separate and/or segregate waste streams
	Waste Transfer/Configuration		Transfer waste streams from source to appropriate receptacles
	Waste Storage/Containment		Temporarily store or contain waste prior to backloading to a treatment or disposal process
	Hazard/Issue Management		As above
Waste Treatment	Waste Receipt		Receive waste
	Treatment Process	Method Selection	Select appropriate treatment method
		Monitor Process	Monitor the conduct of the treatment process (including startup and process conditioning monitoring)
		Control Outputs and Residues	Control the production of treatment process outputs and residues (including bottom/fly ash, slurry, off-gases, emissions, scrubber liquor etc)
		Certification	Certify compliance of treatment process
	Waste Movement, Sorting, Preparation & Storage		Move, sort, prepare and store pre and post treatment process products

Functional Breakdown Element			Description/Comment
Waste Treatment (cont.)	Waste Stream Test		Test treated waste stream to determine suitability
	Hazard/Issue Management		As above

Waste Distribution	Waste Load/Unload		Load and unload waste to/from distribution assets
	Waste Shipment/Movement		Transport waste within the theatre
	Waste Storage/Staging		Temporarily store or stage waste prior to treatment, disposal or further backloading
	Hazard/Issue Management		As above

Waste Disposal	Waste Receipt		Receive waste
	Waste Movement, Sorting & Storage		Move, sort and store waste stream products ready for disposal
	Disposal Process	Method Selection	Select appropriate disposal method
		Monitor Process	Monitor the conduct of the disposal process
		Monitor Capacity	Monitor use of disposal capacity and control process accordingly
		Certification	Certify compliance of disposal process
	Hazard/Issue Management		As above

Appendix B: Functional Requirements – Detailed Description

A detailed description of each of the deployed force waste management functional elements is contained in the following paragraphs.

B.1. Waste Management Planning and Operations

Waste Management Planning and Operations represents the higher-level function of devising, implementing and coordinating a system of deployed waste collection, distribution, treatment and disposal. While the collection and distribution services may be regarded as requiring a logistics approach, by their nature the planning and operation of treatment and disposal services require a scientific/engineering approach.

B.1.1 Waste Management Network Control

Waste Management Network Control contains the functional elements that guide the execution of an ensemble of assets and doctrine connected in a network design, such that the network delivers the deployed force waste management outcomes.

Waste Stream Measurement/Forecast

The deployed forces' Waste Management Plan (WMP) will need to include forecasts of the amount and components of waste generated by the deployed force. Initial quantitative work in this area has been undertaken by URS, however it is important that the ADF endeavour to record the waste produced during exercises and operations so that there is a data source available to assist with the forecasting process. This function will need to be continually executed during a deployment so that the measures in place are those required to effectively, efficiently and sufficiently process all the waste produced.

Measurement and forecasting includes the types and quantities of waste products generated as:

- Solid Putrescible waste (mainly food scraps),
- Solid Inert waste (i.e. non-biodegradable and non-hazardous),
- Grey Water (mainly from washing activities),
- Black Water (toilet waste),
- Gaseous waste (inert, hydrocarbons and others),
- Biomedical waste, and
- Hazardous waste.

Waste Stream Prioritisation

There will be a requirement for the WMP to include priorities for waste management effort and resource application in the deployed setting. Prioritisation will invariably be risk or hazard based and, depending on the deployed context, will be weighted by operational, human health and safety, environmental, social and cost considerations

This function follows on from the waste stream forecasting function and includes consideration of:

- The operational tasking of the deployed force,
- Waste generation rates,
- Concentrations and physico-chemical properties of waste constituents,
- Existing and permissible waste management practices,
- Releases to environmental media,
- Fate and transport of constituents in environmental media (eg persistence),
- Human/ecological exposure potential,
- Human/ecological toxicity potential, and
- Expected climatic conditions.

Site Location

Site location may include consideration of single or multiple collection/transfer points, treatment and disposal sites etc. Any advanced information will assist in the siting of the waste management effort and there will be many factors to be considered including:

- Size of the force and additional personnel (contractors and local) supported by the waste management function;
- Distribution of waste generating sources;
- Existing waste management facilities/capabilities;
- Area availability, land use compatibility and host nation authority;
- Capacity of environment to accept and process waste;
- General meteorological conditions (prevailing winds, expected rainfall, maximum and minimum temperatures, humidity);
- General topography;
- General geological and hydro-geological situation;
- General environmental situation;
- Proximity of force and local population;
- Adjacent activities (eg airfields located near sites that may attract bird life);
- Availability of utilities including water, sewer and electricity;
- Expected duration of the site (for permanent, semi-permanent or temporary locations);
- Flexibility to adapt site to future operational requirements; and
- Failure contingencies.

Network Servicing Arrangements

This function concerns determining arrangements for the flow of waste from source generation through to sites located in the waste management network and the assignment of waste management functions and responsibilities within and for the deployed force. These arrangements will include consideration of:

- Types of waste generated and facilities to be provided;
- Methods of collection, distribution, treatment and disposal available;
- Environmental effects and methods to avoid, remedy or mitigate any adverse effects;
- Operational procedures for controlling and maintaining the network;

- Contingency procedures;
- Administrative arrangements including documentation required, signage;
- Protocols for selection of waste management contractors, contracts and agreements with and between waste management contractors;
- Conditions on approvals and methods to comply with conditions; and
- Service frequencies, routes and coordination.

Asset Location

Whilst site location is significant, the arraying of assets within and between sites is vital to the proper operation of the waste management network. For example, the placement of collection receptacles is vital to reduce any likely contamination to both human health and environmental. The need to provide assets in convenient and secure locations cannot be over emphasised in an attempt to control such matters as human scavengers. The collection locations must be convenient to the personnel disposing of the waste otherwise it will not be correctly disposed of and hence create further waste problems. Additionally, the siting of assets that contribute to the waste stream is significant. In particular the location of kitchens, hospitals, wash-down areas and ablutions in relation to the disposal system can be critical in reducing the risk of disease and the overall cost of the operation.

Asset Deployment/Redeployment

The deployed waste management system must provide assets at the right time, in the right place, with the right capabilities. The importance of the timeliness of waste assets is evidenced by the East Timor operations and the criticism relating to the adequacy of the assets and the timeliness of their arrival[31]. Lead times for the hiring or contracting of assets and services needs to be considered and the means of transporting assets to and within the AO must be established. In general this means that waste management assets should be modular, light-weight and low-volume where possible.

The redeployment must be considered and yet remain flexible. The responsibility for such things as transportation to Australia or a third country and the requirements to achieve customs and quarantine clearance must be allocated to appropriate agencies.

B.1.2 Site Planning and Operations

Site Planning and Operations contains the functional elements required at each site or node in the waste management network.

Site Risk/ Suitability Assessment

Depending on the circumstances of the deployment Site Risk and Suitability Assessment may need to be initially undertaken using historic data, intelligence and guidance designed by SMEs. Many of considerations included under the Site Location (1.1.3) function will need to be examined in greater detail for each specific site with particular emphasis on the assigned function of the site and the potential human health and environmental impacts.

[31] CATDC Mobility BOS East Timor (EM) Engineering Lessons learned Serial 5 d (1) and Annex A to COSC Submission Dated Apr 01 Serial 55

Site Design and Construction

The site design must meet all Australian[32] and International Standards to which Australia is a signatory or has a moral obligation to uphold. The design and construction would normally be conducted through capabilities such as 19 CE Works and the design could be conducted in conjunction with industry establishing both most suitable and best practice. The construction personnel will obviously depend upon the security situation and the type of operations the deployed force are involved with. Army Engineers are capable of construction of the deployed force requirements, however, this becomes an issue of command priorities and the experiences of Timor[33] and Solomon[34] Is was that these were achieved in a less than timely manner.

The design and construction needs to be considered at the early stages of the planning process rather than as an after thought because the waste requirements are a factor from day one rather than day 100. Lengthy approval processes delaying the construction of suitable facilities have a serious affect on operations. If the decision is that civil contractors are to be used then the security situation is of paramount concern[35].

Design needs to be examined from the following perspectives:

- Operational;
- Technical, engineering and scientific;
- Environmental;
- Socio-cultural; and
- Financial, economic.

Site Control

The control of waste sites is of greater concern today than in the past because of the ever increasing demand that the ADF support and be seen to support the local population and environment. Site control includes control of all site operations, and site security, safety and inspections. In Timor the requirement to have an armed guard on the landfill site to prevent the local population scavenging created a significant burden on the deployed force. The actual control of all waste sites is important and depending upon the technologies used will involve personnel in more than simply patrolling any site, but may also require the monitoring of all the effluent/waste systems to ensure that the health risk is minimal for all the deployed and local population. This again may require the employment of other than ADF personnel.

Site control issues may include the following:

- Surface water control;
- Pollution prevention to surface water, groundwater, air and soil;
- Waste peak load and intake control;
- Recording of wastes received, treated, stored and/or disposed;

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[32] Quadripartite Standardization Agreement (QSTAG) 1336 Edition 1 Para 14 a
[33] CATDC Mobility BOS East Timor Engineering Lessons Learned Items 4c (3) & 5d (1)
[34] Discussions with Capt L Mc Lean 19 CEW relating to the approval process for Solomon Is
[35] http://www.abc.net.au/rn/talks/bbing/stories/s963586.htm

- Conservation of airspace;
- Waste reduction, reuse and recycling;
- Control of dust, litter, noise, vermin, odour and weeds;
- Control of emissions and potential contaminants (e.g. landfill gas and leachate);
- Traffic control;
- Fire safety;
- Staffing and training requirements;
- Use of protective clothing and equipment;
- Effective closure and closure management;
- Access to/Security of site;
- Contingency plan activation;
- Conduct of monitoring programs and protocols

If recycling/scavenging systems are employed then they must be made so that resource recovery is limited to specific locations and those that conduct the process do so under safe and clean conditions.

Site Maintenance

The ongoing maintenance of the site may be by either military or contractor personnel and may include repair, performance improvement and other engineering operations. Factors to be considered will include:

- The best practice requirements for the technologies being used;
- The scale of the deployed force and future increases/reductions expected;
- Maintenance of perimeters, fencing and signage;
- Adjustments required because of experience gained during the deployment;
- Any local customs and or sensitivities eg cultural observances;
- Maintenance of access roads;
- Aesthetics; and
- Requests from legitimate authorities.

Site Remediation

This function includes planning, preparing for and completion of site restoration, after-care and closure actions. The planned withdrawal from the site must be carefully considered to ensure that there are no adverse human health and environmental effects. The resultant site must meet the same standards as for Australia and also the sensitivities of the local population in relation to customs and cultures.

Ongoing monitoring and testing may be required at some sites. For example, for landfill there may be the requirement to monitor the site for up to thirty years, or until it becomes a mature, stable site[36] Sites must be examined for any toxic residues and there is a requirement to document all action taken to ensure that in the future proof of all steps and tests undertaken in the remediation process can be identified and substantiated.

Remediation may include consideration of the following:

[36] http://people.howstuffworks.com/landfill.htm 5 Nov 2003 page 10

- Recording of the total waste volumes and weight treated or disposed of through a site along with results of monitoring protocols on closure;
- Development of topographic plans detailing final contours, surface water diversions and drainage controls employed;
- Design of final covers or capping applied to sites including topsoil, vegetative cover and erosion prevention controls employed;
- Notification of closure to local population;
- Any ongoing monitoring protocols for the site;
- Expected maturity date of the site and when it will be rendered safe for alternative uses; and
- Any ongoing rodent or nuisance wildlife control procedures for the site.

B.1.3 Hazard/Issue Management

The Hazard/Issue Management function centres on identifying adverse impacts on achieving the waste management objectives of the deployed force. This includes pre-deployment functions which help identify potential contaminants in a deployed setting, and deployment functions, incorporating assessment and monitoring protocols to determine the likely impact of waste management operations in a deployed setting and to measure actual environmental outcomes.

This function could include the use of sampling and measuring capabilities either as a component of collection, distribution, treatment and disposal technologies or through the use of other separate capabilities. These functions may be integrated in part or in full with the Environmental and Occupational Health function provided through a deployed military health force as an aspect of preventive health. In addition, it should be integrated with any Environmental Performance Reporting the ADF undertakes in a deployed setting in the areas of impact on flora/fauna, land use, impact on aquatic environment, waste generation, soil and water contamination, waste treatment and disposal, and air emissions.

Waste management affects the environment through land use, through pollution with hazardous substances that escape into the air, water and soils. Waste facilities produce greenhouse gases in varying quantities, in the form of methane gas, carbon dioxide, hydrogen sulphide, and non-methane organic compounds from landfill, composting or waste treatment sites. Other influences on the air environment are rain acidification caused by sulphur dioxide and oxides of nitrogen from incineration plants. Waste management also affects the soil, ground and surface waters through leachate escape from landfills, land spreading and waste storage. Leachate may contain persistent, toxic and bio-accumulable compounds, and nutrients that can cause eutrophication. Whatever method is used to treat or dispose of waste, it is invariably (at some point) the environment that is used to dilute, disperse, breakdown or stabilise the waste.

The effect on the environment of all waste created in theatre should be able to be determined prior to deployment. The actual effect may be related to the particular environment and the climate/weather and thus the overall effect may not be apparent until arrival in theatre and may be seasonal. As far as possible the effects should be predetermined with adjustments made to the knowledge base during the deployment. The amount of exposure will depend on the scale and type of operations and whilst these may be anticipated, they will only be fully known in hindsight. The importance of the documenting of the exposure is critical as regards the long term effect on the environment, but also important from the position of future use of the area where the waste was created, stored, processed and transported.

Given the known toxicity of the potential waste the potential for exposure must be identified and, within the constraints of the operational imperatives, the deployed forces will need to develop procedures to ensure that the exposure is kept to a minimum and that procedures are in place to reduce any adverse effects on personnel and the environment. Training and safety issues are raised in QSTAG 1336 and sound training is an issue in reducing the exposure potential.

Assess Human Toxicity/Exposure

This function entails assessing such aspects as acute toxicity/lethality, chronic non-cancer toxicity, genotoxicity/mutagencicity, carcinogenicity, reproductive and developmental toxicity/teratogenicity, irritation and sensitivity.

Assess Ecological Toxicity/Exposure

This function entails assessing acute or chronic toxicity and exposure to aquatic organisms, mammalian species, terrestrial and avian species and plants.

Assess Exposure Potential

This function entails assessing factors such as bioaccumulation, bioconcentration, biotransfer, hydrolysis, nitirification, mobility and waste physico-chemical properties (eg flammability, gas explosive limits).

Assess Operational Aspects

This function entails assessing the impact of waste management operations on combat effectiveness of deployed force.

Assess Other Aspects

This function entails assessing a range of other factors such as public health and safety, legal implications, host nation issues, environmental impacts, nuisance (noise, smell, dust, loss of visual amenity, litter, pest, plagues), biodiversity, aesthetic value and regulatory interests.

B.2. Waste Collection

Waste Collection contains the logistic functional elements for the establishment of effective, efficient and sufficient collection schemes. Focused predominantly at the waste source, this function includes the collection of all waste streams using approved containers and the proper identification of waste.

B.2.1 Waste Identification/Screening

This function includes the actions of identifying, separating and/or segregating, marking and documenting waste streams. The point of waste stream separation is an important decision and, in theory, is most easily achieved at waste source. Such action makes wastes useable or less difficult to treat and/or dispose of, however, the decision will be influenced by operational practicalities. This decision does have knock-on affects to the means of collection, distribution, treatment and disposal employed and their capacity and throughput requirements.

B.2.2 Waste Transfer/Configuration

This function includes the transfer of waste streams in an appropriate manner from sources to appropriate receptacles. Whether this be by permanent or semi-permanent infrastructure (such as in the case of piping/plumbing/run-off drainage for liquid waste) or other means (particular such as those for hazardous, biomedical or quarantine wastes requiring specialised measures) each waste stream requires individual consideration.

B.2.3 Waste Storage/Containment

This function includes the temporary storage or containment of waste prior to backloading to a transfer/collection site, treatment or disposal process. A priority must be to ensure the proper collection and storage of waste in order to minimize risks to both the environment and human health. This will include the employment of suitable containers and the arrangements by which these are inducted into the distribution function.

B.2.4 Hazard/Issue Management

This function is as described at B.1.3, with an emphasis on identifying the impacts of the collection function on achieving the waste management outcomes of the deployed force.

B.3. Waste Treatment

Waste treatment may be required prior to reuse, recycling or disposal of waste stream constituents. The need for treatment and the level and type of treatment will be determined by the requirement of its future use or disposal.

B.3.1 Waste Receipt

At a point of waste treatment this function ensures the proper reception of waste products and includes consideration of matters such as:

- The types of wastes being received, any risks associated with storage/treatment of combinations and segregation requirements as necessary,
- Use of standard fittings and adaptors,
- Transport access,
- Frequency of treatment process use and necessary capability,
- Constraints on the receiving treatment process such as maximum delivery rates,

- Constraints of the transfer process such as pump capacities and pumping rates, and
- Protection for accidental spillage and/or odour release during receipt function.

B.3.2 Treatment Process

Method Selection

The waste treatment method selected is dependent on:

- The waste types to be treated;
- The treatment outcome required - to render the waste innocuous, to reduce hazard or nuisance, to reduce the waste by volume, to reduce the waste by mass;
- The treatment asset status (availability, throughput and capacity, deployability, setup time);
- Treatment resource and energy consumption;
- The preferred mode of implementation (small, mobile or larger, centralized service);
- Likely cost of treatment for various waste types;
- The effectiveness and reliability of method in treating waste;
- Pre-processing requirements (such as the addition of chemical agents, de-watering etc);
- Process safety and reliability, including potential impacts associated with accidental release of/exposure to contaminants;
- Nature of emissions from the process, particularly process effluents, air emissions and residual solids;
- Limitations in the application of the process (eg where the presence of certain materials in the waste would preclude application of the technology);
- Community acceptability of the process (social and cultural) and the preferred mode of implementation;
- Manning and skills requirements; and
- Possible impediments to approval being granted by regulatory authorities.

Monitor Process

Depending on the treatment technology employed, monitoring the conduct of the treatment process can include both the process startup and its continued operation. This may incorporate the monitoring of energy sources or reagents and environmental conditions that facilitate the treatment process and process safety.

Control Outputs and Residues

This function will also be dependent on the treatment technology employed, but includes controlling the production of treatment process outputs (including material and energy for reclamation/recovery) and residues (including sludge, ash, slurry, off-gases, emissions and scrubber liquor). Reclaimed process outputs may be applied to other uses (e.g. treated effluent) and reapplied to other processes (e.g. energy transfer).

Certification

While equipment and process design and specification should support compliant operations, final certification will depend on the correct conduct of the treatment process. This function ensures this certification.

B.3.3 Waste Movement, Sorting, Preparation & Storage

Pre and post treatment, waste stream components and treatment outputs and residues may require movement, sorting, preparation and temporary storage.

B.3.4 Waste Stream Test

Particular waste streams may require some form of testing prior to treatment to determine the suitability of the selected process. In addition, process outputs may require testing.

B.3.5 Hazard/Issue Management

This function is as described at B.1.3, with an emphasis on identifying the impacts of the treatment function on achieving the waste management outcomes of the deployed force.

B.4. Waste Distribution

Waste Distribution contains the logistic functional elements for the establishment of efficient and sufficient distribution schemes.

B.4.1 Waste Load/Unload

This functional element includes the loading and unloading of waste to/from distribution assets. This function may be integral to distribution assets (vehicles, watercraft) or provided separately. Loading may also include consideration of compaction - the threshold question in deciding whether to use compaction or not is whether the gross weight of the transport units would be reached without compaction.

B.4.2 Waste Shipment/Movement

This functions enables the transportation of waste within and from the theatre. It includes such matters as:

- Assignment of appropriate vehicles (road/rail/sea/air),
- Adoption of appropriate transport regulations,
- Driver/coxswain qualifications, and
- Emergency procedures while enroute

B.4.3 Waste Storage/Staging

This function provides for temporary storage or staging of waste prior to treatment, disposal or further backloading.

The volume of storage provided must align with the frequency of pickups, peak waste periods and the impact of any waste sorting or processing undertaken in a location. The maximum storage time depends on such matters as the type of waste, method of containment, storage space available, presence and type of wildlife and seasonal conditions. Storage should be designed and implemented so that wind and vermin (including birds and animals) cannot cause the spreading of wastes and diseases.

This includes local and centralised storage sites, where waste is stored pending final disposal or transportation to permanent storage facilities. Where appropriate, (particularly for hazardous material) storage facilities should be placarded to identify the nature of wastes that are stored in the facility and posted with signs warning of the dangers, and restricting access to authorized personnel only. Protection of these facilities may be a consideration, depending on the treat and the material stored. Some hazardous materials may be more attractive as terrorist materials than others.

B.4.4 Hazard/Issue Management

This function is as described at B.1.3, with an emphasis on identifying the impacts of the distribution function on achieving the waste management outcomes of the deployed force.

B.5. Waste Disposal

This is the transfer of waste to an approved waste processor for long term storage, destruction or recycling. A principle that is likely to apply in a coalition environment is that forces cannot take advantage of easier and cheaper standards of disposal of another coalition member, or the host nation, to abrogate their responsibilities.

B.5.1 Waste Receipt

At a point of waste disposal this function ensures the proper reception of waste products and includes consideration of matters such as:

- The types of wastes being received, any risks associated with storage/treatement of combinations and segregation requirements were necessary;
- Transport access;
- Constraints on the receiving disposal process such as maximum delivery rates and overall capacity;
- Constraints of the transfer process such as pump capacities and pumping rates; and
- Protection for accidental spillage and/or odour release during the receipt function.

B.5.2 Waste Movement, Sorting & Storage

This function includes the movement, sorting and storage of waste stream products ready for disposal.

B.5.3 Disposal Process

Method Selection

The waste disposal method selected depends on such matters as:

- The waste types to be disposed of;
- The disposal system capacity;
- The preferred mode of implementation (eg natural control or engineered landfills; trench, area or ramp);
- Likely cost of disposal for various waste types;
- The effectiveness and reliability of method in disposing of waste;
- Pre-processing requirements;
- Process safety and reliability, including potential impacts associated with accidental release of/exposure to contaminants;
- Nature of emissions from the process, particularly process effluents;
- Limitations in the application of the process (eg where the presence of certain materials in the waste would preclude application of the technology);
- Community acceptability of the process and the preferred mode of implementation;
- Possible impediments to approval being granted by regulatory authorities;
- Asset availability and deployability; and
- Manning and skills requirements.

Monitor Process

Depending on the disposal process employed, monitoring the conduct of the process can take many forms. This may incorporate the monitoring of energy sources or reagents and environmental conditions that facilitate the disposal process, process safety and environmental outcomes.

Monitor Capacity

This function monitors the use of disposal capacity and controls the process accordingly.

Certification

While equipment and process design and specification should support compliant operations, final certification will depend on the correct conduct of the disposal process. This function ensures this certification.

B.5.4 Hazard/Issue Management

This function is as described at B.1.3, with an emphasis on identifying the impacts of the distribution function on achieving the waste management outcomes of the deployed force.

Appendix C: Waste Management Technologies and Systems – A Qualitative Assessment

Table 3 – Waste Treatment and Disposal Technologies and Systems

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
1.Landfill	Permanent final destination of waste that is requiring no further treatment (See also Biodegredation)	May be local landfill sites that could be used	Not applicable	Constructed by Army Engineers with advice from industry	Can be constructed by Army engineers with no further specialised training.	Low	If possible could be used for solid waste including sludges and other processed wastes. In Timor there was a requirement to permanently guard the landfill site. There is a requirement to ensure that no toxic leachate will escape from the site. **Note: Landfill will give an ongoing responsibility for up to 30 years.**
2.Biodegradation	The process of enhancing the breakdown of solid wastes particularly in landfills	A process rather than a technology	Nothing to deploy	Simply construction for landfill and that is where the process can be used	Some monitoring of the landfill required and training would be required	Minimal	This process would be suitable for a landfill but really is the monitoring of the landfill and undertaking as necessary measures such as increasing the temperature or moisture content. The aim is to stabilise the landfill as quickly as possible.
3.Composting	Solid Putrescible waste mainly food scraps	Constructed by Army Engineering resources	Constructed on site	Standard Engineering deployed equipment	Military members with standard Army training	Minimal	Will be weather dependent and may require security to prevent scavengers of any description

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
4.Aerobic/ Anaerobic/ Anoxic Waste Water Treatment Process	Aerobic elimination of organic matter, oxygen may be pumped in or the water stirred. Closed tanks for the Anaerobic process where methane is produced, anoxic process removes nitrate	Commercially available	Deployable as general stores and engineering specific stores	Some specialised equipment required and can be assembled or constructed by Army engineers	Specialised training required for the operation of the system	Low	Could be used by a deployed static force that is too large to tap into local effluent disposal if indeed it is available. Could be operated by trained Mil or Contract Personnel
5.Deep Bore disposal	Construction of a deep bore, below all the water tables that may be encountered.	There may be one of these already in the region	Not applicable for the bore, but the equipment is deployable	Could be constructed by Army engineers using specialised equipment to bore and pumping equipment	Could be constructed by Army engineers with specialised training on the equipment taken into theatre	Medium	Mainly used for waste water, but may involve some legacy issues
6.Evaporation	This can be either natural in the case of evaporation ponds or through the application of heat	Commercially available	Transported to and or constructed on site	Some specialised equipment and some standard eg backhoes and bulldozers	Military personnel with some specific training for equipment type	Low	The ponds are simple, but may not be suitable in all locations, the specialised equipment will require trained personnel and in both cases the resultant sludge will require disposal
7.Sedimentation	The process of allowing the flow of the water to slow down sufficiently to allow finer particles to settle. This settled material is called sludge	Commercially available	Fully deployable	Can be constructed using engineering stores	Part of normal engineering training with in the Army	Minimal	Will be used in conjunction with evaporation process
8.Filtration	Filters used to remove suspended solids, particularly in black and grey water	Commercially available	Transported to and constructed on site	Some specialised equipment and some standard eg piping	Military personnel with some specific training for equipment type	Low	This is a standard type operation that could be operated by either military or civilian contractors may have to be used in association with evaporation ponds

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
9.Chlorination	The use of chlorine in the waste treatment process prior to the water being passed into the local water system such as a river	Commercially available	Deployable	Specialised equipment	Training required and not a standard skill required by uniform personnel	Medium	This process may be necessary depending upon climate and storage capacity that can be developed; there is the requirement for large volumes of chlorine
10.Oil Separation Gravity	Oily water is allowed to settle and the specific gravity allows the oil to be skimmed off from the surface (eg Spinifex)	Commercially available	Easily deployable and some construction by engineers required	Simple but specialised equipment in conjunction with tanks or ponds	Minimal training required	Minimal	Often used in conjunction with Cyclones as a first step to remove the bulk of the easily separated oil, if large quantities of water, the area used could be considerable
11.Oil Separation Cyclones	Oily water is separated by a centrifuge	Commercially available	Easily deployable	Simple but specialised equipment with standard piping required	Minimal training required	Low	Often the second stage of above and used particularly for grey water from vehicle washdown/ maintenance areas. Note these areas need to be constructed so that grey water can easily be recovered.
12.Reverse Osmosis	Passing of water through a semi permeable membrane could be used in the treatment of both black water and or grey water	Commercially available	Many available units	The units are totally specialised, but other parts, ie the delivery and distribution pipes are standard stores items	Military personnel require operator and maintenance training	Significant	Possibly suitable, costs both equipment and personnel are high compared with evapor-ation. The waste material must be disposed of.
13.Chemical Toilets	Treat waste in a "closed" system, simply another form of toilet.	Commercially available	Simply deployable as part of the stores system	No special equipment required	Only simple training required, can be used by anyone	Low	Easily deployable and could be used in any static environment, further forward than the force HQ. The waste product will need to be properly disposed of.

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
14.BiPu Toilets	Another form of toilet	Commercially available	Held as a stores item in some units	Use normal engineering equipment to dig trench	No special training	Low	The waste remains in the ground requiring no further treatment.
15. Septic Tanks	Primary treatment of black water	Commercially available or can be manufactured on site	Deployable as engineering stores or individual units	No special equipment required	No special training	Minimal	As a soakage trench is required the use of septic tanks will depend on soil and length of deployment; they may also need to be removed at end of use.
16.Gas Phase Chemical Reduction	Chlorinated hydrocarbons including dioxins are chemically reduced to methane and hydrogen chloride	Commercially available	Not deployable	Very Specialised	Specialised training	Medium to high cost for treatment of waste	Suitable for the destruction of hazardous and medical waste, Australian site is in Western Australia
17.Incineration in specialised furnace	Destroys solid waste and sludges and high tech to reduce toxic by products	Commercially available	Containerised version available	Very specialised and single use	Could be manned by trained military personnel	Medium to high	International broad based pressure to end this disposal method because of the toxicity of gases and slag produced[37]
18.Incineration in specifically constructed trench	Destroys solid waste and sludges and high tech to reduce toxic by products	Constructed by Army Engineering resources	Constructed on site	Standard engineering deployed equipment	Military members with standard Army training	Minimal	This type of destruction is banned in most Aus States and many parts of the world
19.Plasma Arc	Effectively a more technically advanced form of incineration	Commercially available	Can be containerised for transportation	Very specialised	Considerable operator training required	Very high	Suffers as for incineration, the pressure on incineration includes the use of plasma arc methods, the control of toxic gases is very specialised

[37] CMPS&F Environment Australia Appropriate Technologies for the Treatment of Scheduled Wastes Review Report Number 4 November 1997 Chapter 3.1 "…high temperature incineration…not considered to be an option for the treatment of solid wastes in Australia at this time. While high temperature incineration is a proven technology, it has been found to be difficult to implement in Australia due to public concern."

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
20.Pyrolysis	Thermal degradation of waste in the absence of air to produce char, pyrolysis oil and syngas	Commercially available	Not deployable	Very specialised	Very skilled operators required	High	Not suitable for a deployed force because gases produced need treatment and slag may be difficult to deal with
21.Ion Exchange	Process of atoms or molecules that are charged (+or-) attach themselves to an exchange media within a 'vessel' as the waste water passes through the vessel	Commercially available	Easily transportable	Specialised equipment with appropriate chemicals and or resins	Relatively simple training	Low/ Medium	Unlikely to be required because the waste water is unlikely to have high concentrations of specific impurities that would make this a suitable method of removal
22.Precipitation	Chemical reactions so that dissolved contaminants form insoluble solids which precipitate	Commercially available	Could be deployed	Specialised equipment but also special chemicals required.	Specialised training would be required in the use of appropriate chemicals	Medium, with consider-able cost of chemicals	Unlikely to be required as a high concentration of specific pollutants would be present from the deployed force operations; also the residue would need to be appropriately disposed of
23.Air Flotation	The use of air bubbles to remove fine suspended material from an aqueous suspension	Commercially available	Deployable	Specialised equipment	Some specialised training	Medium/ High	The main removal would be for oil and greases from grey water and these could be more easily and cheaply removed by using oil separation techniques . This system would seem to be overkill
24.Chemical Fixation	Conversion of waste into less soluble form and then fixing it into solid form eg cement	Commercially available	Yes, transporting of chemicals and lime, cement etc in containers	Standard Engineering deployed equipment such as concrete mixers and NBC clothing and equipment	Military members with standard training	Low	Labour and time intensive and a site suitable to conduct the process and room for the drying of the fixed waste (weather issues)

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
25.Neutralisation	Method used to neutralise waste (fluid) that is strongly alkaline or acidic generally from industrial production processes	Commercially available	Systems designed to be transportable and would fit inside a container	Simple but specialised equipment	Minimal training	Low	Unlikely to be required because there is low likelihood of waste water from the deployed force requiring this treatment
26.Ozonation	The use of Ozone to disinfect waste water, the Ozone is manufactured on site then passes through the waste water	Commercially available	Systems designed to be transportable and would fit inside a container	Specialised equipment	Specialised training	High	The costs in both money and personnel would be high and would still require further treatment eg ponds
27.Chemical Reduction	Use of chemicals to reduce harmful chemicals to a less harmful chemical and then this can be removed in a second process	Commercially available	Small systems are designed to be transported	Specialised equipment and appropriate reduction chemicals	Specialised training	High (mainly because of the chemicals)	Unlikely to be required and the introduction of extra chemicals creates another supply stream for the Deployed force.
28.Wet Air Oxidation	Treatment for waste waters, sludges and slurries	Commercially available	Not Deployable	Very Specialised	Trained operators	High	Unlikely to be needed as the chemicals such as acrylonitrile, dichloroethane, vinyl chloride, phenols, carbon tetra chloride, cyanides and toluene are unlikely to be present in significant quantities rendering this process unnecessary.[38]
29.Base Catalysed Decomposition (formerly called	Treats liquid or solid waste decomposing the toxic elements to	Commercially available	Technically deployable, practically very	Very specialised	Considerable training required – would need to	High	Unlikely to be required to treat waste from a deployed force[39]

[38] Note: It would be wise to ensure that cleaning solvents and other chemicals used by the deployed force are as environmentally friendly/ benign as possible. Chemicals that may be a concern may need to be collected and separated from the rest of the grey water.

[39] Discussion with BCD Technologies 07 3203 3400 indicated that they have completed some soil remediation for the ADF but considered that their technology would be unlikely to be required for a deployed force, because of its transient nature and the likely limited contamination.

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
dechlorination)	generally non toxic material. Mainly used for treatment of contaminated soils and such things as pesticides		difficult		be contractors		
30.Chemical Neutralisation	This involves a simple process of breaking down the chemical agents through use of common, low-cost industrial chemicals, usually in a solution of water. The downside of this is it use of lots of water and may produce substantial volumes of residual waste that have to be further treated.	Commercially available[40]	Proposed to be deployable	Very Specialised	Specialised training and not likely to be a military personnel operation	High	Unlikely to be required to treat waste from a deployed force
31.Electrochemi-cal Oxidation	A wide range of wastes has been identified as being suitable for this type of treatment, including pharmaceuticals, explosives, cyanides, phenols, organometallics, pesticides, dyestuffs and pathogenic materials. Oils and plastics have so far been hard to process.	Commercially available and still developing	Not at this time, but may be produced in the future	Specialised	Specialised training and not likely to be a military personnel operation	High	Adapted particularly to the nuclear industry and is unlikely to be suitable for the destruction of wastes produced by a deployed force.

[40] http://www.tbe.com/environmt/nonstockpile.asp Teledyne Brown Engineering a Company with contracts to destroy US stockpile of chemical weapons

Name	Description	Availability	Deployability	Specialised Equipment	Personnel	Cost	Suitability
32.Solvated Electron Technology	The SET TM process uses solvated electron solutions to reduce organic compounds to metal salts and the parent (de-halogenated) molecule. Solvated electron solutions, which are strong reducing agents, are formed by dissolving alkali or alkaline earth metals such as sodium or calcium in anhydrous liquid ammonia.	Commercially available	Mobile systems are available	Specialised	Specialised training and not likely to be a military personnel operation	High	Unlikely to be required to treat waste from a deployed force because waste streams of material suited to this process are unlikely to be produced.
33.Supercritical Water Oxidation	The agent and energetics hydrolysate are destroyed using a supercritical water oxidation or SCWO unit. SCWO subjects the hydrolysates to very high temperatures and pressures, breaking them down into carbon dioxide, water, and salts.	Commercially available	Mobile systems are available	Specialised	Specialised training and not likely to be a military personnel operation	High	Unlikely to be required to treat waste from a deployed force because waste streams of material suited to this process are unlikely to be produced. If however Gas Phase Chemical reduction is used then this process may be used by others as a pretreatment

Appendix D: Waste Management Modelling -- An Annotated Bibliography[41]

Characterising and Estimating Waste Streams

[1] Haith D.A., (1998). Materials Balance for Municipal Solid Waste Management. Journal of Environmental Engineering, Vol 124:67-75

This paper describes a spreadsheet model (MSWFLOW) developed as an accounting procedure for determining impacts of management decisions on the physical scale and productive outputs of a municipal solid-waste system. The model tracks the disposition of 50 different waste products and includes source reduction, recovery (recycling and composting), waste-to-energy (WTE) combustion and landfilling. Outputs from the calculations include mass and volume of waste generated, collected, and diverted by source reduction or recovery; physical scale (daily mass and/or volume) of the recovery and combustion facilities; landfilled mass and associated volume requirement; potential (maximum) annual landfill gas production; and net electrical power production from the combustion facility. The spreadsheet is demonstrated by evaluations of several alternative management strategies for municipal solid waste from a typical US city with a population of 100,000.

Assessment of Waste Management Impacts

[2] Alvim-Ferraz M.C.M., Afonso S.A.V., (2003). Incineration of Different Types of Medical Wastes: Emission Factors for Gaseous Emissions. Atmospheric Environment, Vol 37:5415-5422

Previous research works showed that to protect public health, hospital incinerators should be provided with air pollution devices. This paper reports the first Emission factors estimated for CO, SO_2, NO_x and HCl, associated with the incineration of medical waste, segregated in different types. The results showed that those Emission factors are strongly influenced by incinerated waste composition, directly affected by incinerated waste type, waste classification, segregation practice and management methodology.

[3] Eriksson O., Carlsson Reich M., Frostell B., Bjorklund A., Assefa G., Sundqvist J.O., Granath J., Baky A., Thhyselius L., (2004). Municipal Solid Waste Management from a Systems Perspective. Journal of Cleaner Production, forthcoming article

In this paper different waste treatment options for municipal solid waste are studied in a systems analysis. Different combinations of incineration, materials recycling and biological treatment of biodegradable waste, are studied and compared to landfilling. The study covers the use of energy resources, environmental impact and financial and environmental costs.

[41] Annotations are drawn largely from abstracts relating to each specific article

[4] Hydrologic Evaluation of Landfill Performance
US Army Corps of Engineers
www.wes.army.mil/el/elmodels/helpinfo.html
Accessed 5 Apr 04

The Hydrologic Evaluation of Landfill Performance (HELP) model as developed by US Army Engineer authorities facilitates rapid estimation of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may result from the operation of a wide variety of landfill designs.

[5] Environmental Management – Life Cycle Assessment – Principles and Framework (AS/NZS 14040:1998), Standards Australia/Standards New Zealand

This standard provides the general framework, principles and requirements for conducting and reporting life cycle assessment studies. These studies are used for assessing the environmental aspects (resource use, human health, and ecological consequences) and potential impacts associated with a product throughout its life (ie cradle-to-grave).

Assessment of Waste Management System Cost Benefit

[6] Miranda M.L., Hale B., (2004). Paradise recovered: energy production and waste management in island environments. Energy Policy, forthcoming article

This study investigates the competitiveness of WTE technologies using a cost benefit structure. It examines production and environmental costs, and concludes that modern pollution control technology, high-energy production costs, and limited availability of suitable landfill sites render WTE facilities an economically and environmentally attractive option.

Multi-criteria Assessment of Waste Management Technologies and Systems

[7] Morrissey A.J., Browne J., (2004). Waste Management models and their application to sustainable waste management. Waste Management, Vol 24: 297-308

This paper reviews a range of models currently being used in the area of municipal waste management and highlights a range of benefits, limitations and shortcomings. The paper considers three model types being those based on cost benefit analysis, life cycle analysis and multi-criteria assessment. The latter are dealt with in a more comprehensive and favourable fashion.

[8] Haastrup P., Maniezzo V., Mattarelli M., Mazzeo Rinaldi F., Mendes I. Paruccini M., (1998). A decision support system for urban waste management. European Journal of Operational Research, Vol 109:330-341

This paper describes a decision support system for urban waste management in a regional area, to be used for evaluating general policies relating to waste collection and for identifying areas suitable for locating waste treatment and disposal plants. The decision support system allows the generation and evaluation of alternatives with respect to features such as environmental consequences. The paper describes the identification and collection of relevant information, the structuring of a database, the design of combinatorial optimisation algorithms for solving the core location problem, the study of models for evaluating the different alternatives and their framing in a multi-criteria decision model.

[9] Karagiannidis A., Moussiopoulos N., (1997). Application of Electre III for the Integrated Management of Muncipal Solid Wastes in the Greater Athens Area. European Journal of Operational Research, Vol 97:439-449

This paper presents an application of multi-criteria analysis in the area of municipal solid waste management for the Greater Athens Area. For the case study area, a concise family of 24 evaluation criteria is proposed. Through these, five selectively composed alternatives for the integrated management of household waste are compared and ranked by the Elimination and Choice Translating Reality (ELECTRE) multi-criteria analysis method.

[10] Skordilis A., (2004). Modelling of Integrated Solid Waste Management Systems in an Island. Resources, Conservation and Recycling, forthcoming article

This paper presents a system's engineering model for the strategic planning of an integrated solid waste management system. The model was developed in the context of an island with a tourism focus, and combines environmental, financial, technological and social criteria in the assessment of options.

[11] Hokkanen J., Salminen P., (1997). Choosing a Solid Waste Management System Using Multicriteria Decision Analysis. European Journal of Operational Research, Vol 98:19-36

This paper reports on the application of ELECTRE multi-criteria analysis method in the context of choosing a solid waste management system for a region of Finland. Eight criteria were settled upon for the analysis, which the authors suggest represent a comprehensive, operational, non-redundant and minimal set of criteria that would represent higher level objectives.

[12] Powell J.C., (1996). The Evaluation of Waste Management Options. Waste Management & Research, Vol 14:515-526

In this paper the multi-criteria assessment of six waste disposal options (landfill, incineration and refuse-derived fuel [RDF] each with or without recycling) are considered in relation to 15 criteria. The study is a site-independent assessment of these options.

[13] Lahdelma R., Salminen P., Hokkanen J., (2002). Locating a Waste Treatment Facility by Using Stochastic Multicriteria Acceptability Analysis with Ordinal Criteria. European Journal of Operational Research, Vol 142:345-356

This paper describes the application of an ordinal multi-criteria method in the context of choosing a location for a waste treatment facility in a region of Finland. Seventeen criteria were applied to determine the best of 4 location alternatives within Finland.

[14] Cheng S., Chan C.W., Huang G.H., (2003). An integrated multi-criteria decision analysis and inexact linear programming approach for solid waste management. Engineering Applications of Artificial Intelligence, Vol 16:543-554

This paper reports on an integration of multi-criteria assessment analysis and integer programming methods to support selection of an optimal landfill site and a waste-flow allocation pattern (movement of waste between locations) in a region of Canada. The integer programming method provides a number of optimal site cost components that are used as input to one of the 12 qualitative and quantitative criteria employed in the multi-criteria assessment.

[15] Seo S., Aramaki T., Hanaki K., (2003). Evaluation of Solid Waste Management System Using Fuzzy Composition. Journal of Environmental Engineering, Vol 129:520-531

This paper presents an approach to evaluating a solid waste management system in a fuzzy environment. The approach employs linguistic variables, fuzzy numbers and the multi-criteria, Analytical Hierarchy Process. Linguistic variables are used to represent the degree of appropriateness of decision criteria, which are vague or uncertain. These linguistic variables are translated into fuzzy numbers to reflect their uncertainties and aggregated into the final fuzzy decision value using a hierarchical structure. The study employs the basic criteria of environmental impact potential, resistance of local inhabitants, total cost, ease of maintenance and durability of alternative to assess competing waste management approaches.

Planning and Allocating Resources in a Waste Management System

[16] Everett J.W., Modak A.R., (1996). Optimal Regional Scheduling of Solid Waste Systems. I: Model Development. Journal of Environmental Engineering, Vol 122:785-792

This paper presents a linear programming model designed for the long term scheduling of disposal and diversion options in a regional integrated solid waste management system. As an optimisation model, it can be used to determine what types of integrated solid waste management programs to implement, and when to implement them, in order to minimise costs over a long planning period. The model can incorporate multiple communities, landfills and incinerators and the possible implementation of numerous collection and diversion options. The model also provides a means to determine the volume of land filled waste.

[17] Modak A.R., Everett J.W., (1996). Optimal Regional Scheduling of Solid Waste Systems. II: Model Solutions. Journal of Environmental Engineering, Vol 122:793-799

Modak and Everett present the results of their linear programming model [16] applied to a hypothetical case study.

[18] Chang N., Shoemaker C.A., Schuler R.E., (1996). Solid Waste Management System Analysis with Air Pollution and Leachate Impact Limitations. Waste Management & Research, Vol 14:463-481

This paper presents an optimisation model concerning site location and resource allocation in a solid waste management system. The model incorporates both economic costs and environmental impacts.

[19] Abou Najm M., El-Fadel M., (2004). Computer-based interface for an integrated solid waste management optimization model. Environmental Modelling & Software, forthcoming article

The paper presents a linear programming model to optimise the flow of waste streams in a network of waste management. The model includes waste generation source details, intermediate treatment facilities (including processing sites, biological and thermal treatment facilities) and landfill sites. A spreadsheet-based interface to the optimisation model is also described along with a case study applied from North Lebanon.

[20] Caruso C., Colorni A., Paruccini M., (1993). The Regional Urban Solid Waste Management System: A Modelling Approach. European Journal of Operational Research, Vol 70:16-30

This paper concerns the development of a location-allocation model for planning an urban solid waste management system. The results of the model are the number and location of waste disposal plants, specifying the technology adopted, the amount of waste processed and the service boundary of each plant.

[21] Barlishen K.D., Baetz B.W., (1996). Development of a Decision Support System for Municipal Solid Waste Management Systems Planning. Waste Management & Resources, Vol 14:71-86

This paper describes a decision support system that combines knowledge-based system components with spreadsheet, optimisation and simulation models to assist with: waste forecasting, technology evaluation, recycling and composting program design, facility sizing, location and investment time, waste allocation and waste management system analysis using simulation.

[22] Solano E., Ranjithan R., Barlaz M.A., Brill E.D., (2002). Life Cycle Based Solid Waste Management I: Model Development. Journal of Environmental Engineering, Vol 128:981-992

This paper describes a linear programming model to assist in identifying alternative solid waste management strategies that meet cost, energy and environmental emissions objectives.

[23] Solano E., Ranjithan R., Barlaz M.A., Brill E.D., (2002). Life Cycle Based Solid Waste Management II: Illustrative Applications. Journal of Environmental Engineering, Vol 128:981-992

Solano et al present the results of their linear programming model [22] applied to a hypothetical case study.

Simulating Waste Management System Performance

[24] Bhat V.N., (1996). A Model for the Optimal Allocation of Trucks for Solid Waste Management. Waste Management & Resources, Vol 14:87-96

This paper describes a simulation-optimisation model that assists in the allocation of waste collection trucks in a municipal waste management system.

[25] Everett J.W., Dorairaj R., Maratha S., Riley P., (1998). Curbside Collection of Recyclables II: Simulation and Economic Analysis. Resources, Conservation and Recycling, Vol 22:217-240

This paper employs a simulation model to investigate the effect of waste collection method and route characteristics on overall route time.

[26] Wilson B.G., Baetz B.W., (2001). Modeling Municipal Solid Waste Collection Systems Using Derived Probability Distributions I: Model Development. Journal of Environmental Engineering, Vol 127:1031-1038

This paper presents a derived probability model that can be used to estimate vehicle and labour requirements for a municipal solid waste collection system. Simulation was used as a comparative tool to test the probability model outcomes.

Assessment of Alternative Technology and Waste Management Strategy Options

[27] State Government of New South Wales, (2000) Report of the Alternative Waste Management Technologies and Practices Inquiry. Office of the Minister for the Environment: Sydney

This report provides the outcomes of a public inquiry formed to investigate current and emerging waste management technologies and practices, taking into account the principles of ecologically sustainable development. The Inquiry assessed four separate classes, covering 14 types of waste management technologies including mechanical separation, biological, thermal and landfill technologies.

[28] United Nations Environmental Program, (1999). A Directory of Environmentally Sound Technologies for the Integrated Management of Solid, Liquid and Hazardous Waste for Small Island Developing States (SIDS) in the Pacific Region. UNEP – International Environmental Technology Centre

This report provides a directory of environmentally sound technologies for waste management plus those currently successfully being used in Small Island Developing States within the Pacific Region. Technologies cover the categories of solid waste, hazardous waste and liquid waste or wastewater.

Waste Management Decision Support Systems

[29] MacDonald M.L., (1996). A Multi-Attribute Spatial Decision Support System for Solid Waste Planning. Computers, Environment and Urban Systems, Vol 20:1-17

This paper describes the results of a study into solid waste management planning processes and the development of a specific spatial decision support system (SDSS) to address the multi-attribute and geographical nature of solid waste systems. It describes the analytical tools both for developing solid waste management plans and for evaluating a number of impacts associated with a plan. The SDSS includes experts systems and model management capabilities to supply, organize and analyse relevant data, and a GIS to help planners understand the spatial nature of particular programs and how they may impact the public and the environment.

Appendix E: Waste Management Technologies – A Quantitative Assessment Method

E.1. Introduction

The Alternative Waste Management Technologies and Practices Inquiry was established[42] by the State Government of New South Wales to investigate current and emerging waste management technologies and practices, taking into account the principles of ecologically sustainable development. The Inquiry was focused on municipal waste, commercial and industrial waste, and construction and demolition waste.

In their report the Inquiry assessed four separate classes of waste management technologies covering 14 types:

- Mechanical Separation Technologies
    - Material Sorting
    - Waste Separation
- Biological Technologies
    - Land Application
    - Open Windrow Composting
    - Vermicomposting
    - Enclosed Composting
    - Anaerobic Digestion
    - Fermentation
- Thermal Technologies
    - Incineration
    - Pyroloysis/Gasification
    - Waste Melting
- Landfill Technologies
    - Conventional Wet Landfill
    - Conventional Dry Landfill
    - Bioreactor Landfill

E.2. Assessment Objectives and Criteria[43]

This appendix sets out the multi-criteria assessment method and scoring basis used to evaluate these selected technology systems. The assessment was based on four objectives:

- Technical Issues,
- Environmental Issues,
- Social Issues, and
- Economic Issues.

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[42] Established in July 1999 and reported in April 2000

[43] The information contained in this part of the report is drawn directly from State Government of New South Wales (2000), Report of the Alternative Waste Management Technologies and Practices Inquiry

These objectives are broken down further into the criteria described in the following paragraphs, together with an assessment as to the applicability of the criteria to deployed force conditions. Where possible a quantitative score (out of 5, with 5 being the most favoured) was allocated against each criterion on the basis of actual field performance. This was not always possible due to the early stage of development of some of the technologies.

E.2.1 Technical Issues

The technical issues of the systems under review are considered from four aspects:

- **Technology Maturity** is an assessment of the relative development of the technology in terms of the reliability of the technology in treating waste, which is also indicative of operational risk. The scoring system from this issue below is based on the scoring system used by the German Federal Environmental Agency:

5	Used successfully for purpose at commercial scale for many years with at least 80% annual operational time.
4	Used at commercial scale over a one to two year period (~ 10,000 hours operation) with expert assessment of environmental, technical and economic issues.
3	Successful operation of pilot plant over several months using waste with some analysis of environmental, technical and economic issues.
2	Operation of all parts of an experimental or pilot plant with waste.
1	Concept of a new process structured in a logical order prior to operation of a pilot plant, testing of some process components

Assessment – Applicable to deployed force conditions

- **Input Quality Flexibility** is the ability of the technology system to treat varying waste streams, which is important as waste is a heterogeneous feedstock. This measure covers both immediate heterogeneity/homogeneity requirements of the technology, and the ability of the technology to process successfully waste inputs which may vary in composition over time. No direct quantitative score could be developed for this issue, so a scoring system was developed as below:

5	Technologies applicable to all waste streams including hazardous materials.
4	Technologies applicable to all waste streams except hazardous materials.
3	Technologies applicable to treating or recovering value from the bulk of waste.
2	Technologies applicable to treating only one waste stream (e.g. organics).
1	Technologies applicable to only one waste type (e.g. food waste, biosolids).

Assessment – Applicable to deployed force conditions

- **Input Quantity Flexibility** refers to the adaptiveness of the technology to input quantity variations over time. Considerations include technical, financial and employment implications of swings in supply of resource for processing. The assessment is based on the following scoring:

5	Able to handle large variations in waste input quantity (100%) rapidly with little capital expenditure/overcapitalisation.
4	Able to handle moderate variations in waste input quantity (50%) with little capital expenditure/overcapitalisation.
3	Able to handle moderate variations in waste input quantity (25%) with moderate capital expenditure/overcapitalisation.
2	Able to handle some variation in waste input quantity (10%) with moderate capital expenditure/overcapitalisation.
1	Unable to handle variations in waste input quantity.

Assessment – Applicable to deployed force conditions

- **Local Availability** of technology and expertise is an assessment of the ability for the technology to be adopted for use in Australia, including the extent to which expertise and specialised equipment would need to be imported to support the use of the technology.

5	Australia has world class expertise in development, construction and operation of the technology.
4	Local expertise and operational experience, but leading edge development work or critical equipment would need to be imported.
3	Some local expertise or experience, but expertise and equipment would need to be imported.
2	Limited local expertise, most expertise and/or equipment would need to be imported to support operation.
1	No local expertise or operations, all would need to be imported.

Assessment – Applicable to deployed force conditions

E.2.2 Environmental Issues

- **Resource Conservation** is a critically important environmental consequence of waste treatment and processing. Recycling and reprocessing substitutes previously extracted, refined and processed materials for virgin raw materials. Many studies have shown that the resultant conservation of resources is a significant environmental benefit. Greatest benefit accrues in treating and reprocessing finite resources and elaborately transformed materials. It must be stressed that both the technology and the accompanying waste management practices must be regarded as a 'system' in order to achieve these benefits. However, in this analysis each technology is considered in isolation and for application to the resource it is bested suited to treat. The assessment is based on the following scoring:

5	High potential savings in terms of materials and/or energy.
4	Moderate potential savings in terms of materials and/or energy.
3	Small or neutral savings in terms of materials and/or energy.
2	Moderate potential loss of resource materials and/or energy.
1	High potential loss of resource materials and/or energy.

Assessment – Not Applicable to deployed force conditions

- **Solid Residues** are the residual solid wastes that require disposal at the completion of a waste processing or disposal operation. These vary widely depending on the level of contamination in the incoming waste, so the level of source separation practices has a large influence. The amount and nature of the solid residues is an important measure of the sustainability of the process and where it fits in the waste management hierarchy, as a process that produces large amounts of solid residue has poor sustainability and would be at the bottom of the hierarchy. The assessment of solid emissions is as follows:

5	Negligible residues – residual wastes are low (land application, new oxidation).
4	Minor residues – minor residual wastes, less than 20% of incoming waste (incineration, pyrolysis/gasification, material sorting).
3	Significant residues – residues dependant on level of contamination in input waste being processed (enclosed composting, open windrow, composting, anaerobic digestion, fermentation, vermicomposting).
2	Considerable residues – large amount of residues of marginal value (waste separation).
1	Major residues – very little reduction of solid waste through process (landfill).

Assessment – Applicable to deployed force conditions

- **Greenhouse Gas** emissions include carbon dioxide and monoxide, methane, non-methane organic compounds, flurocarbons and nitrogen oxides. Greenhouse gas emissions are of concern in relation to the sustainability of various waste management options. The greenhouse impacts of various waste technologies are rated as follows:

5	Beneficial
4	Moderately beneficial
3	Negligible
2	Moderately detrimental
1	Detrimental

Assessment – Applicable to deployed force conditions

- **Air and Water Emissions** based on the relative emission probability and consequence. These have been assessed according to the probability/consequence matrix outlined in ASNZ 4360:1999 (Risk Management):

5	Insignificant
4	Minor
3	Moderate
2	High
1	Extreme

Assessment – Applicable to deployed force conditions

E.2.3 Social Issues

- **Community Involvement in Resource Conservation** refers to the extent to which the community is able to become associated in some way with activities associated with the technology and the broader practice involved. This reflects the importance accorded by the community making a contribution to the recycling of waste resources and, to some extent, to comprehend and identify with the fate of disposed materials. The assessment of citizen and business involvement potential uses the following scoring:

5	High involvement by the community providing a contribution to local or regional community capital.
4	High involvement by the local community, but modest involvement at a regional level.
3	Modest involvement at local and regional community levels.
2	Minor scope for community involvement and participation.
1	No scope for community involvement and participation.

Assessment – Not Applicable to deployed force conditions

- **Public Perception** is an assessment of the broad community attitude to the technology. Such attitudes are usually formed through a combination of lengthy operating experience, pollution control record and technology complexity; a complex amalgam of perceived risk and benefit. While no direct polling was undertaken, assessment was made on the basis of previously conducted public opinion surveys, public reaction to existing or proposed waste technologies, and public reaction to waste technologies examined overseas. However, cultural differences prevent direct application of overseas attitudes and therefore these observations are used to inform rather than develop the evaluation. The assessment is based on the following scoring:

5	High public confidence in the technology.
4	Moderate public confidence in the technology.
3	No clear attitude to the technology, mostly due to newness.
2	Poor perception of the technology by some sections of the community.
1	Broadly based hostility towards the technology.

Assessment – Applicable to deployed force conditions

- **Employment Impacts** refers to the scope for job creation directly and indirectly as a result of engagement of the technology. The assessment of local employment potential is based on the following scoring:

5	Significant direct/indirect employment opportunities involving a variety of skill levels and opportunities for further development.
4	Moderate direct/indirect employment opportunities involving a variety of skill levels.
3	Moderate direct/indirect employment opportunities.
2	Low direct and indirect employment opportunities.
1	Very low employment opportunities.

Assessment – Applicable to deployed force conditions but with scoring scale reversed (being a proxy for ADF personnel requirements)

E.2.4 Economic Issues

- **Net cost per tonne** of waste input is estimated from the capital and operating cost estimates of technology. The assessment of net cost/tonne of waste input is based on the following scoring:

5	Less than $50
4	$50 > $100
3	$100 > $150
2	$150 > $200
1	More than $200

Assessment – Applicable to deployed force conditions

- **Cost/Scale Sensitivity** examines the sensitivities of costs to variations in the scale of the facility, and the extent to which the technology is driven to require large scale operation in order to achieve the necessary economies of scale. The assessment of cost/scale sensitivity is based on the following scoring:

5	May be small, medium or large scale operation, with little variation in processing cost.
4	May be small, medium or large scale operation with moderate variation in processing cost.
3	Medium to large scale operation best for economies of scale.
2	Large scale operation necessary to achieve economies of scale.
1	Large scale operation is the only feasible configuration.

Assessment – Applicable to deployed force conditions

- **Net Benefits per tonne** of waste input has been developed from Australian and International estimates of revenue from sale of resources, on a net tonne of input basis. The assessment of net benefit per tonne of waste input incorporates the following scoring:

5	More than $70
4	$50 > $70
3	$30 > $50
2	$10 > $30
1	Less than $10

Assessment – Not Applicable to deployed force conditions

- **Market Availability** for products is a measure of the maturity and stability of the markets for products produced from waste, and the relative position of the products in these markets. For example, energy recovered from landfill gas has a large proven market as 'green power'. The assessment of market availability is based on the following scoring:

5	Products with a large proven market.
4	Products with a varying market.
3	Products with a marginal market.
2	Products now waste with some potential for future markets.
1	Products with marginal or negative value.

Assessment – Not Applicable to deployed force conditions

E.3. Objective and Criteria Weightings

The Inquiry report included the authority's assessment of the relative importance of each of these 17 criteria in the evaluation of alternative technologies. This relative importance is translated as a numerical score appearing in the 'Weighting for Combination A' column of Table 4.

As outlined above it is considered that five of the criteria as proposed by the Inquiry are not directly applicable to the deployed military setting. Removal of these criteria from the assessment is represented by the numerical weights appearing in the 'Weighting for Combination B' column of Table 4. Finally the last column of Table 4, 'Weighting for Combination C', includes the weights for criteria applicable to deployed forces along with 'Employment Impact' but on the basis that the Inquiry's scoring regime for this criteria is reversed. The normally positive employment impact of job creation might be important to councils embarking on a waste management program, but Defence does not wish to create the requirement for extra personnel in theatre.

Table 4 - Assessment Criteria with Non-Normalised Weightings

Criteria Class	Criteria		Weighting for Combination A	Weighting for Combination B	Weighting for Combination C
Technical	Technology Maturity	T1	0.08	0.08	0.08
	Input Quality Flexibility	T2	0.07	0.07	0.07
	Input Quantity Flexibility	T3	0.06	0.06	0.06
	Local Availability	T4	0.04	0.04	0.04
Environmental	Resource Conservation	E1	0.06	0	0
	Solid Residues	E2	0.06	0.06	0.06
	Greenhouse Gas Emissions	E3	0.05	0.05	0.05
	Risk Of Water Emissions	E4	0.04	0.04	0.04
	Risk Of Air Emissions	E5	0.04	0.04	0.04
Social	Community Involvement	S1	0.08	0	0
	Public Perception	S2	0.08	0.08	0.08
	Amenity Impact	S3	0.05	0.05	0.05
	Employment Impact	S4	0.04	0	0.04
Economic	Net Costs Per Tonne Input	Ec1	0.08	0.08	0.08
	Cost/Scale Sensitivity	Ec2	0.07	0.07	0.07
	Net Benefits Per Tonne Input	Ec3	0.05	0	0
	Market Availability	Ec4	0.05	0	0

E.4. Technology Scoring Against Individual Criteria

As a separate process each of the 14 technologies was scored for each of the 17 criteria using the Inquiry's scoring regime. The results appear in Table 5.

E.5. Results

Using a simple weighted sum the Inquiry generated a single numerical score for each of the 14 technologies. This was done by using (normalised) weightings from Table 4 and combining them with the scores from Table 5. The results of the three weighting combinations are shown in Table 6.

For all three combinations, the highest ranked method was material sorting, and the second highest was enclosed composting. While this assessment might suggest that the slightly different priorities of Defence still tend to point to similar choices in waste management technologies to those used by industry, the weightings of the criteria most definitely should be reassessed. A set of pair-wise comparisons for all of the criteria should be performed to generate robust weightings for the assessment. Also, the suitability of the waste disposal technologies is influenced heavily by the scale of the operation so more specific scenario-based assessments could be useful.

The assessments using the three combinations produced only slightly different results. While not all of the technologies are substitutable technologies (eg material sorting is not a direct substitute for landfill), the assessment does present the relative preference of biological, thermal and landfill technologies. Combination A suggests a preference order of biological followed by thermal and landfill. Combination C suggests perhaps an even preference for biological and landfill, followed by thermal.

Adopting this method would also call for further analysis to determine the sensitivity of the results to changes in the criteria weightings.

Table 5 - Technology Scores by Criteria

	Technology Maturity	Input Quality Flexibility	Input Quantity Flexibility	Local Availability	Resource Conservation	Solid Residues	Greenhouse Gas Emissions	Risk of Water Emissions	Risk of Air Emissions	Community Involvement	Public Perception	Amenity Impact	Employment Impact*	Net Costs per tonne input	Cost/scale Sensitivity	Net Benefits per tonne input	Market Availability
Mechanical																	
Material Sorting	5	3	3	5	5	4	4.5	5	4	5	4	3	5/1	3.5	3	4	4
Waste Separation	4.5	4	3	4	4	2	4	3	3	1	3	3	2/4	5	3	1	2
Biological																	
Land Application	4	1	3	4	4	5	4	3	4	1	2	4	2/4	5	3	1	3
Open Windrow Composting	5	2	4	5	4	3	3	3	2	4	3	2	2/4	5	4	2	3
Vermi-Composting	4	2	3	5	4	3	4	3	3	4	4	3	2/4	5	3	3	3.5
Enclosed Composting	5	2.5	3	4	4	3	4	5	4	4	4	3	3/3	4	3	2	3
Anaerobic Digestion	5	2	3	3	4.5	3	4	2	3	3	3	3	3/3	3.5	3	2	4
Fermentation	3.5	2	3	2	4	3	4	3	3	3	3	3	3/3	3	3	2	5
Thermal																	
Incineration	5	4	3	2.5	2	4	3	4	2	1	1	2	2/4	1.5	1	2	4
Pyrolysis/Gasification	3.5	3	3.5	3.5	3	4	3	3	2	3	3	3	3/3	3	3	2	4
Waste Melting	2.5	5	3	3	3	5	3	4	2	2	3	3	2/4	2.5	3	2	4
Landfill																	
Conventional Wet Landfill	5	4	5	5	1	1	2	2	3	2	2	1	2/4	5	5	1	4
Conventional Dry Landfill	5	4	5	5	1	1	3	3	5	2	2	1	2/4	5	5	1	1
Bioreactor Landfill	4	4	5	4	1	1	2	3	3	2	2	2	2/4	5	5	1	4

* The first number represents the Inquiry's score, the second number represents reversal of the score as applied by this brief

Table 6 - Overall Technology Results

	Combination A score	Combination A rank	Combination B score	Combination B rank	Combination C score	Combination C rank
Mech1-Material Sorting	0.092	1	0.084	1	0.082	1
Mech2-Waste Separation	0.069	7	0.074	5	0.075	5
Bio1-Land Application	0.069	9	0.072	7	0.073	7
Bio2-Open Windrow Composting	0.076	4	0.073	6	0.074	6
Bio3-Vermi-composting	0.079	3	0.075	4	0.075	4
Bio4-Enclosed Composting	0.080	2	0.079	2	0.078	2
Bio5-Anaerobic Digestion	0.072	5	0.069	10	0.068	11
Bio6-Fermentation	0.069	8	0.064	13	0.063	13
Therm1-Incineration	0.056	14	0.057	14	0.057	14
Therm2-Pyrolysis/Gasification	0.069	6	0.067	12	0.067	12
Therm3-Waste Melting	0.068	10	0.068	11	0.069	10
Landfill1-Conventional Wet Landfill	0.067	12	0.071	8	0.072	8
Landfill2-Conventional Dry Landfill	0.067	11	0.076	3	0.077	3
Landfill3-Bioreactor Landfill	0.066	13	0.071	9	0.071	9

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Stephen Baker and Bruce Vandepeer

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19. ABSTRACT
This report examines a range of science and technology issues concerning waste management for deployed land forces. Within this waste management context, the report outlines the functional requirements of a deployed force, the status of Australian research and development, deployable technology options, and approaches to systems modelling.